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THE UNIVERSITY OF ALBERTA

SOIL ERODIBILITY & EROSION IN PART OF THE BOW RIVER BASIN, ALBERTA

by

© SHIU-HUNG LUK

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Soil Erodibility and Erosion in Part of the Bow River Basin, Alberta," submitted by Shiu-hung Luk in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Geography.

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TO OUR CHILDREN

ABSTRACT

This thesis attempts to collect basic data on soil erodibility and to test the applicability of laboratory simulation results to field studies of soil erosion. Few similar studies exist.

Within five sub-drainage basins, 17 one square-mile (2.59 km²) units in the Bow River Basin above Bassano Dam were selected for study. These areas encompass the landscape spectrum from the mountains to the plains in Southern Alberta.

Following field mapping of the units according to a parametric system 153 samples were collected. Samples were tested for soil erodibility, aggregate size, texture, organic carbon content, and bulk density. For soil erodibility tests, the Edmonton-pattern rainfall simulator was used. Rainfall intensity was held constant at 102 mm/hr. Each sample had three runs of 30-minutes each, and soil moisture, slope angle, and cover density were varied. For the first two runs, total soil loss ranges from 19.7 to 2 490 g/m².

The data were analysed by multiple regression techniques, and a simplified prediction equation using slope angle, cover density, aggregate size, and organic carbon content as the independent variables was established. About

80 percent of the total variation in laboratory simulated soil loss is explained by this equation.

Thirty erosion plots of about 1 m^2 in size were installed in the fall of 1972. These plots were only serviced one to three times in 1973. A more intensive sampling program for 16 plots was carried out in the summer of 1974. Total amount of measured soil loss for the season ranges from 6.1 to 94.5 g/m^2. About 40 to 50 percent of the total variation in measured soil loss is explained by the independent variables: rainfall amount, cover density, aggregate size, and bulk density.

With reference to constant rainfall amount and cover density, the laboratory simulation model was tested against observed field soil loss. The correspondence is generally good, and the coefficients of correlation range from 0.5 to 0.7.

Since the laboratory simulation model is substantiated by field data, the results are generalized to cover all 17 units studied. Plotting of unit soil erodibility shows a reduction in erodibility from the plains to the foothills and a slight increase again towards the mountains. The pattern appears to be explanable in terms of regional environmental characteristics. Unit soil erosion potential shows a similar pattern.

Drainage basin relative erosion rates were evaluated by

considering mean soil erodibility, mean ground slope, mean cover density, and relative rainfall erosivity. The computed results seem consistent with available sediment yield records.

From these results, the deduced present rate of sedimentation at the Bassano Dam is much lower than the unadjusted long term mean. Major sources of sediment supply are (a) excessively erodible glacial or alluvial deposits and bedrock along major drainage channels in the upper foothills; (b) steeply sloping coulee sides, ditches, and cultivated land on moderate slopes in the prairies; and (c) cultivated and poorly grazed areas in the foothills where rainfall erosivity and sediment delivery rates are considerably higher than in the prairies.

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I have received invaluable assistance from many individuals, agencies, and institutions in completing this study. They deserve more than just brief mentioning that is possible here.

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Mr Geoff Lester and Mr Kim Davis drew the figures. Mr Jack Chesterman and Mr Randy Padan prepared the photographic prints. Mr Rex Ding and Mr Si-ming Li provided field assistance.

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SYMBOLS

a	Empirical coefficients
A	Area
b	Constant term
C	Organic carbon content
D	Raindrop size
D_{50}	Median drop size
DL	Double logarithm to base 10
ϵ	Error term
E_k	Kinetic energy
E_s	Splash loss (erosion)
E_t	Total loss (erosion)
E_w	Wash loss (erosion)
F	Infiltration
G	Aggregation (WSA >0.5mm)
GER	Gross erosion rate
I	Rainfall intensity
k	Empirical constant
K	Percent bare ground
L	Slope length
log	Logarithm to base 10
m-tons	Metric tons
n	Sample size
θ	Slope angle
P	Precipitation

r	Coefficient of Correlation
R	Coefficient of multiple correlation
R_d	Direct rainfall
R_f	Rainfall amount
s	Standard deviation
SE	Soil erodibility
SEP	Soil erosion potential
SL	Soil loss
S_p	Splash proportion
μ	Micron
U	Runoff
V	Evaporation
W_p	Wash proportion
WSA	Water stable aggregates
$\bar{x}$	sample mean

CHAPTER ONE

INTRODUCTION

1.1 Erosion Research

The problem of accelerated erosion has existed since very ancient times and the fall of many early civilizations may be attributed to the ravaging effects of soil erosion. The perception of this problem can be traced back in history to as early as the 5th Century B.C. in China (Hsin 1958). In North America, the problem was recognized in the early seventeenth century (McDonald 1941).

Scientific research on erosion only began with Ewald Wollney in the 1860's in Germany (Baver 1938). Plot studies of runoff and erosion in North America were started in the 1910's and 1920's.[1]

In the following 50 years, research concentrated in two main areas, one practical, the other theoretical. In relation to practical needs for tackling imminent erosion problems in cultivated areas, large amounts of soil loss data had been collected since the 1930's. Various factors of topography, rainfall, crop cover and management, and soil were related to measured soil loss. Musgrave (1947) summarized some of the earlier findings while Wischmeier &

---

[1] e.g. Sampson & Weyl 1918; Duley & Miller 1923

Smith (1961) assembled all then available data and developed the now well-known UNIVERSAL SOIL LOSS EQUATION.

Data for non-cultivated areas were very limited. With an increasing need of exploiting land and mineral resources, a greater amount of research in the non-cultivated areas was undertaken. The growing awareness of the urban pollution problem spurred similar research in populated areas.

Theoretical research was directed at the physical processes affecting erosion. Middleton (1930), examined physical and chemical properties of the soil affecting its erodibility. Laws (1940, 1941) and Laws & Parsons (1943), showed the relationship among raindrop size, rainfall intensity and rainfall energy. Ellison (1945) demonstrated the then unknown important effect of raindrop splash on erosion. Relationships of raindrop size to intensity and type of rainstorms were further examined (Rogers et al 1967, Kinnell 1973). The mechanics of overland flow under simulated rainfall in the field and in the laboratory were investigated (Emmett 1970), as were conditions under which surface crusting is developed on bare soil surfaces (Bryan 1974).

These two areas of research, practical and theoretical, are interrelated. Most recent studies are attempts to examine detailed relationships between selected variables and soil loss so that the findings will also throw light on the physical processes involved (e.g. Meeuwig 1970, Farmer & Van Haveren 1971, Bryan 1974).

1.1.1 Land Erosion and Sediment Yield

Erosional processes occur when soil particles are detached, entrained, and transported by erosive agents such as water, ice, and wind. The result is soil loss. The present study is confined to water erosion. Within a drainage basin, eroded soil particles may either be deposited in low-lying areas in the basin or be removed from the basin as sediment load. The long term average sediment load at the basin outlet is the sediment yield of the basin. Since the proportion of eroded to removed soil particles, or 'sediment delivery ratio', varies from basin to basin (Roehl 1962), sediment yield and land erosion are not necessarily correlated although under homogeneous environmental conditions a broad regional relationship may pertain.

Sediment yield is the output of the drainage basin system. The slopes and drainage networks, responding to inputs of rainfall, supply and transport sediment. The physical processes that are responsible for sediment yield include rainsplash, overland flow, gullying, bank erosion, bed scour, and various forms of mass wasting (creep, slips and slumps). But the magnitude and frequency of occurrence of these processes vary considerably. Rainsplash is by far the lowest in magnitude (in terms of effect on sediment yield) but probably the highest in frequency of occurrence.

While the sediment load being carried past a certain point by a river reflects erosion in the basin above that point, it reveals neither the major sources of the sediment nor the relative significance of the various erosional processes responsible for this sediment load. An understanding of the relative rates of sediment yield or soil loss and their controlling factors requires on-site measurement of erosion under a variety of field conditions. The investigation of the relative significance of erosional processes necessitates detailed experimentation in the field and in the laboratory.

1.2 The Research Problem

1.2.1 Background

The Bassano Dam (Fig. 1-5) was constructed on the Bow River, a major tributary of the South Saskatchewan River, about 80 km downstream from Calgary in 1912. The main purpose of the dam was to supply water to the Eastern Irrigation District. In 1971 the reservoir behind the dam was almost completely filled with sediment. Hollingshead, Yaremko, and Neill (1973) estimated that the annual sediment yield of the watersheds draining into the reservoir is 65.5 m-tons/km^2. The gross drainage area of 19 710 km^2 was used for this computation and no adjustment was made for upstream storage in the Ghost, Glenmore, and Bearspaw Reservoirs.[2] Data were not available to give any indication of the sources of this sediment yield. The Research Council of Alberta launched a broad scale investigation of this problem. The present study concentrates on one aspect of this larger investigation, soil erodibility and soil erosion potential and their relevance to sediment yields.

1.2.2 Erosion and Related Studies in Alberta

Much is written about wind erosion in the prairies but research on water erosion has been limited. Mean soil loss of the 10 years' plot record at St. Albert shows a variation from 0.6 m-tons/km^2 for virgin soil to 184 m-tons/km^2 for wheat and fallow rotation (Toogood 1963). Toogood & Newton (1950) and Toogood (1963) concluded that from the agricultural point of view soil erosion by water in the province is not a serious problem. However, these are conservative estimates because the soil studied was a deep, highly aggregated Black Chernozem, which is one of the most resistant soils to erosion in the province.

Campbell (1970) measured erosion rates using small plots at the Steveville badlands. By extrapolation, the average rate is 1 540 m-tons/km² for the barren sites and 22 m-tons/km² for the vegetated sites.

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[2] On the Bow above Bassano Dam, Ghost Dam was constructed in 1929 with a storage capacity of 94 x 10^6 m^3. In 1933, the Glenmore Dam was constructed on the Elbow just above its confluence with the Bow. The Glenmore Reservoir behind the Dam has a capacity of 28 x 10^6 m^3 and since then was used to supply water to the City of Calgary. In 1954, the Bearspaw Dam was constructed on the Bow above the City of Calgary. The capacity of the reservoir is 25 x 10^6 m^3 (Neill et al 1970).

The potentially devastating result of erosion in Alberta can be demonstrated in the Swan Hills (St. Onge & Lengellé 1971). Plot studies reported by Wyldman & Poliquin (1973) indicate a very high seasonal rate of 6 480 to 20 000 m-tons/km².[3] The high erodibility of the Swan Hills material : fine sandy clay to weathered shale with coarse fragments is demonstrated. Similar weathered bedrock are rated more erodible than glacial till deposits in the area (Kathol & McPherson 1974).

'Soil' erodibility ratings were investigated by Rutter (1968) in the Forest Reserve. Various glacial deposits were ranked according to an estimate of their relative infiltration rate, grain size characteristics, carbonate cement, binding strength of silt and clay and, therefore, erosion hazard. The carbonate content criterion was used in a study of land-vegetation typology in the upper Oldman basin (Jeffrey _et al_ 1968). Unfortunately these ideas were not tested quantitatively and no clear distinction was made between the erodibility of the parent materials, such as different types of till, and the soils developed from them.

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[3] These rates are extrapolated from 4 plots' data of size 15 m² at 30 percent slope and over 4 summers, 1968-1971.

Quantitative tests of soil erodibility of mainly prairie soils were investigated by Bryan (1974) using laboratory rainfall simulation techniques. Generally soil erodibility increases with increasing climatic aridity. Although soil loss values determined in the laboratory have no absolute significance, the fact that 84 percent of the samples tested exceeded those of annual soil-loss on agricultural lands of 5 tons/acre or 1 120 m-tons/km² (Hudson 1971) gives some indication of the high erosion potential of Alberta soils.

Various studies on infiltration rates show that because of the normally low rainfall intensities in Alberta and high initial infiltration rates, surface runoff is unlikely to occur during most summer storms (Verma & Toogood 1968, Beke 1969, Spence 1972). However, comparison of rainfall intensity and infiltration rates measured by standard double-ring infiltrometers are not realistic because water, not rainfall, is used and sealing and other effects due to rainsplash are neglected (Branson, Gifford, & Owen 1972). Antecedent moisture content of the soils is a further variable. For the soil moisture regime in Alberta, a low intensity storm might cause some runoff in the spring but probably not in mid-summer.

1.2.3 Research Frontier

Even for rainfall erosion, the relative erodibilities of Alberta soils are not quantitatively defined. The relationship of soil properties to erodibility is only partially tested in the laboratory and not known in the field.

Above all, the applicability of the laboratory rainfall simulation technique in studying erosion and erosion potential to field situations has never been tested quantitatively. Only very limited research on this topic has been carried out anywhere and most are comparisons with natural rainfall characteristics and field rainfall simulators. Recently, Barnett & Dooley (1972) reported that for prediction purposes the use of simulated erosion data in the field approximated erosion data resulting from natural rainfall. A similar result was reported by Young & Burwell (1972).

1.2.4 Objectives & Scope

The specific objective of the present study was, through the use of laboratory simulation and field measurements, to develop and test a soil erodibility predictive equation relevant to sediment yields. This required collection of data on variations in soil erodibility in the study area; collection of data on spatial and temporal variations in soil loss by on-site field measurement and laboratory simulation studies; relating these variations to the conditions under which erosion took place; and testing the significance of the soil loss model developed from laboratory data with respect to field data collected.

This study is only concerned with rainfall erosion. Erosion due to wind and snowmelt runoff are not considered, though it is recognised that they may contribute significant amounts of sediment.

1.3 Area of Study

The watersheds draining into the Bassano Reservoir in the Bow River Basin were examined in this study. Considering the possible contribution of erosion studies to the future siting of an alternative dam, only the watersheds in the basin below Bearspaw Dam were studied.

This area of about 10 000 km^2 includes the mountains, foothills, and plains topography found in this part of Alberta (Fig. 1-2). The western limit coincides with the continental divide, marked by prominent peaks rising to 3 000 m above sea level. About 23 km east and northeast of the continental divide is the Front Range (Highwood Range) with peaks generally at 2 700 m. Between lies an intermountain area with an average elevation of about 2 000 m.

The eastern slope of the Front Range is demarcated by a sharp break in slope. Eastwards lie the inner and outer foothills areas. Still further east are the Great Plains of the continental interior. The boundary between the foothills and the plains is very indistinct. Roughly it follows the line between Calgary and High River, and generally coincides with the 4,000 ft (1 220 m) contour.

1.4 Methodology & Sampling

1.4.1 General

Soil samples from the three physiographic zones were collected and tested in the laboratory using simulated rainfall. Slope, cover density, and moisture conditions were varied to provide some information on the relationship of these variables to erosion potential. Selected soil properties of the tested samples were analysed to provide the basis for evaluating how variations in the material factor affects soil loss rate.

Statistical analyses of these data, together with known theories concerning the mechanics of erosion, were used to develop a laboratory soil loss prediction model.

Suitable erosion plots were used to collect field data in the same areas. Unfortunately, because of the rough terrain in many parts of the study area, the use of the same rainfall simulation technique was prohibited and recourse was made to natural rainfall. Again a variety of physiographic zones, soil and landuse types were covered. The laboratory model was then applied to the conditions under which the field data were collected and compared to the observed values.

Three physiographic zones : mountain, foothills, and plains, each with its distinctive environmental characteristics, are covered in the study area. They occupy an area of 800, 3 400, and 5 800 km² respectively. Because sediment yield data were collected at basin levels, it is convenient to select for study representative drainage basins within each physiographic zone. Areas occupied by each selected basin are shown in Fig. 1-3. In each basin, one-square-mile units were selected for study. The location of the units were found in Fig. 1-5. Units wer further subdivided into 'sites' by field mapping. The areas of these 'sites' generally range from 0.01 to 0.1 km². Erosion plots of size 1 m² and sampling points of an area of 0.1 m² are located within selected sites. The sampling hierarchy described above is shown in Fig. 1-3.

1.4.2 'Basin' Level

Three conditions governed the selection of the sample basins : accessibility, sediment yield data, and physiographic zone.

A number of map sources* were used to compile an access map of the study area. It indicated that access is limited west of a north-south line drawn through the town of High River. Given this constraint, basins in which access to more steeply sloping ground is provided were given priority.

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* Alberta County Maps Nos. 2 & 16; Alberta Municipal District Maps Nos. 31 & 44; Canada Topographical Maps (1:250 000) Nos. 82-I, 82-J, 82-O, & 82-P; Provincial Access Series, Department of Lands & Forest (1:253 440) No. 82-O/J

Reported sediment yield data of medium-sized drainage basins are limited. Sampling of suspended sediment at the Highwood station near its mouth (Fig. 1-4) by Canada Water Survey only began in 1972. A project funded by the Research Council of Alberta (Abrahams & McPherson 1972) collected sediment yield data at 50 stations in southern Alberta, and in order to coordinate with this latter project and to be able to eventually evaluate erosion potential from their data, only basins with this sediment yield data available were used.

To investigate variations in erosion among the three zones : mountain, foothills, and plains, sample basins have been selected in such a way that areas belonging to these three 'provinces' are included.

Within the constraints imposed by these three factors, five drainage basins were selected for study. They are Cataract Creek, Three Point Creek, Pekisko Creek, Stimson Creek, and West Arrowwood Creek (Fig. 1-5).

1.4.3 'Unit' Level

The NTS grid system has been extended into the Forest Reserve areas and the one-square mile areas (equivalent to 2.6 km^2 approximately) form the basic unit of study. Within each selected basin, available information on bedrock geology, surficial deposits, soils, vegetal cover or landuse, and other physiographic characteristics such as elevation and mean gradient of slope were assembled. Then, units were selected to provide a suitable coverage of the various physical characteristics of the 'unit' to produce a comparable number of units in each physiographic zone weighed according to area. Selected sample units of the basins are shown in Fig. 1-5.

1.4.4 'Site' & 'Plot' Levels

One to three locations were selected from each unit for the installation of erosion plots. The number of plots reflected the degree of variability of the general erosional environment in the unit. The number of units and plots by drainage basin is given in Table 1-1.

1.5 Summary

The background and relevance of this investigation to erosion research are presented. As an illustration of the research done and in order to bring into focus existing knowledge in this field, pertinent literature is reviewed in the following chapter. Some attempts are made to compare results from different sources.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Remarks

Literature relevant to this project can be classified into four categories : (1) field and laboratory techniques; (2) physical characteristics of the area, and (3) factors affecting erosion and (4) soil loss prediction.

Category (1) will be reviewed in Chapter 4 and category (2) discussed in Chapter 3. The last two categories will be treated here. Other relevant literature will be related to the points under discussion.

2.2 Soil Properties

The soil properties that affect its erodibility are threefold: infiltration, moisture content, and other surface characteristics; aggregation and particle size; organic content; and other chemical properties.

Many infiltration equations have been developed (Amorocho 1967). The classical model of Horton (1933, 1940) related rainfall, runoff, and infiltration : the higher the percentage of infiltration in relation to runoff, the smaller is the amount of soil loss. Hendrickson (1934) found that very thin layers of silt and clay sediments applied in suspension quickly blanketed flat sand surfaces and effectively clogged the pores, impeding entry of water into the soil. Ellison (1945) demonstrated the relationship of infiltration rate and soil splash and raindrop erosion. Splash erosion increased as infiltration rate decreased. The reduction in infiltration rate caused by a given amount of splash varied with soil type. Peele (1937a) also emphasized the rate of water percolation as an index of soil erodibility. Nazatov (1974) showed quantitatively that 'infiltration rate' is a valid index of soil resistance to erosion.

In most of the infiltration/runoff studies prior to the 1960's, the Hortonian model was applied with infiltration usually defined as rainfall minus runoff (e.g. Adams et al 1958). This trend is still apparent (Gifford 1972). Kirkby & Chorley (1967), following Whipkey (1965), suggested an alternative: the throughflow model, which is considered to be applicable in forested or densely vegetated areas. 'Overland' flow, as defined in the Hortonian sense, may occur locally, such as at slope bases, even though the rainfall intensity rate does not exceed the infiltration rate. This may have relevance to erosion by overland flow in forested areas (Pierce 1967).

In addition, the partial area and variable source area models of streamflow production have been developed. These see areas proximate to the water courses and other areas as being the areas likely to contribute to runoff formation. In forested watersheds, Hewlett & Hibbert (1965) suggested that runoff production was achieved by the expansion of saturated zones along the valley floors and over the lower portions of the adjacent slopes.

Horton (1933) recognized the significance of soil moisture content by dividing storms into two classes upon the basis of the time of their occurrence in relation to previous rains. Initial soil moisture content has a greater effect on rate of infiltration during the first 20 minutes of simulated rainfall than any other factor (Neal 1937). Tisdall (1951) suggested all measurements of initial infiltration should be accompanied by determination of antecedent soil moisture.

Baver (1937) noted the importance of effective soil moisture during precipitation. Runoff and erosion were not related to either amount of rainfall (Rf), rainfall intensity (I), or their product (Rf x I). However, with the inclusion of the effective moisture factor (M), variations in runoff and erosion were significantly related to the variable Rf x I x M.

Later studies suggest that high moisture content may be only one possible cause of low infiltration rates and therefore overland flow. Some soils are water repellent, a property related to soil-wettability (Krammes & DeBano 1965) for which there are many possible causes. Fire temperature and type of vegetation are two common ones.[1] Several studies revealed the effect of this property on soil erodibility. Osborn & Pelishik (1964) treated three plots with a wetting agent and found the amount of soil loss to be much smaller on the treated plots than three identical untreated plots. Hussain _et al_ (1969) found a causal relation between presence of pine litter and water repellency. Retention of rainfall in pine plots was significantly less than in brush plots.

Duley (1939), studying surface characteristics, suggested that the formation of a surface sealing layer results from the beating action of raindrops and the 'assorting' action of runoff water by which the finer particles are fitted around the larger ones to form a relatively non-pervious seal. McIntyre (1958b) identified the dominant processes for the formation of surface crusting as aggregate breakdown by raindrop impact and slaking, wash-sorting and interstitial straining of fine particles. Clay seal formation was attributed to raindrop impact. Bryan's (1973) experiments suggest that surface clay seals form only after rainfall ceases. As clay seals were not observed during rainfall, his hypothesis is possibly correct. Reduction in infiltration during rainfall could be attributed to blocking of pores by interstitial straining and swelling of clay minerals on saturation and an increase in soil bulk density and strength (Epstein & Grant 1967, Tackett & Pearson 1965) and decrease in permeability (McIntyre 1958a, 1958b) of the soil surface during rainfall. The effect of the development of surface crusting on erodibility is reduction in splash loss (McIntyre 1958b) and amplification of wash loss (Epstein & Grant 1967).

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[1] See for example _Proc. Symp. Water-Repellent Soils._ University of Calif., Riverside, May 1968.

For soil aggregation, Lutz (1934), reported in a study of soil erodibility that a relatively non-erodible clay soil was highly granulated into large, stable and porous aggregates, in contrast to the lower content of small, compact granules, and the dispersed condition of an erodible sandy clay loam. A comparative study of runoff and soil loss from sandy loam and clay loams by Peele et al (1945), showed that the sandy loams were more erodible. Relatively impermeable surface layers resulting from the beating action of raindrop formed more quickly on the sandy loams than on the clay loams due to degree of aggregation of the soil and degree of dispersion of the soil colloids.

A point often ignored is that soil aggregation is a very complicated process, reflecting variations in topography, climate, vegetation and landuse (Kemper & Koch 1965), and local aspect (Balci 1968). At the site level, clay content and organic content are the dominant controls. Hartmann & DeBoodt (1974) emphasized the influence of moisture. Variations in clay mineralogy and soil chemistry are also involved (Harris et al 1966).

Yoder (1936) developed the technique for measuring size distribution of water stable aggregates. Since then, many indices of aggregation have been proposed (Bryan 1971). A number of these indices relate to soil erodibility (Woodburn & Kozachyn 1956; Adams et al 1958; Farmer & Van Haveren 1971; Toogood & Lynch 1959; Yamamoto & Anderson 1973, Bryan 1969, 1974). Although it is unlikely that any one of these indices is universally applicable (Bryan 1968b) the conditions under which one index becomes more efficient than others are yet to be investigated.

The effect of primary particle size on soil erodibility is complex because most surface soils in nature exist in aggregates. A differentiation, therefore, should be made between effect of particles in dispersed and in undispersed conditions.

In a dispersed condition, sand is the most detachable and clay the most transportable (Ellison 1947). Ekern (1950) showed that the greatest amount of splash is associated with fine sand (0.25 to 0.175 mm). Mazurak & Mosher (1968) studied the detachment rate of primary particles and aggregates under simulated rainfall. For raindrops of 5.1 mm, detachment rate is highest for fine sand (210u - 105u) for primary particles. A low detachment rate for larger particles was explained by the mass of these particles and for smaller particles by their greater cohesion.

Farmer (1973), evaluated the relative detachability of particle sizes by comparing the amount in each soil class in the pretreatment soil and the splashed soil. Without overland flow, particle sizes in the range of 110µ - 1 450µ were the most susceptible to detachment by raindrop impact. With overland flow, the susceptible size range was 219µ - 2 034µ.

For splash erosion therefore, these three studies generally agree that fine sand has the highest detachability. However the actual size of highest detachability may be related to raindrop size. Farmer's (1973) study is complicated by the fact that aggregates were used although original and eroded fraction particle size are compared. The explanation offered by Mazurak & Mosher above (1968) appears realistic.

For undispersed particles, i.e. aggregates plus particles, Osborn (1954a) found that fine-textured and sandy soils have high detachability. Mazurak & Mosher (1970) note that peak detachment rate produced by 5.1 mm raindrops lies in the range of 2.36 to 1.68 mm for silty clay loams. Moldenhauer & Long (1964) reported that fine sand is highly erodible but because of high infiltration capacity the resultant amount of soil loss is small. On the other hand, silty clay possesses very stable aggregates but because the fines tend to form a surface seal, there are high rates of runoff and soil loss.

These studies are not comparable because erodibility of aggregates varies from one soil to another. The amount of organic matter present affects stability of aggregates (Peele 1937b). Also clay and organic content may vary with size of aggregates (Garey 1954). Yet, it is reasonable to assume that for comparable amounts of organic matter, aggregates of sandy soils are less stable and therefore are somewhat more erodible than clayey soils.

Bulk density and voids ratio of a soil affect its infiltration and erosion characteristics. Adams et al (1958), examined the effects of variations in bulk density on erosion under simulated rainfall. Wash loss shows a significant negative correlation with bulk density but not splash erosion. Meeuwig (1965) found a significant positive relationship between bulk density and soil loss, although this relationship is only applicable to the fine-textured soils studied. Work on coarse textured soils by Packer (1951), revealed that soil bulk density exerted very little influence on soil loss. Yet, to Farmer & Van Haveren (1971), soil bulk density was one of the significant factors affecting raindrop splash erosion for both sandy and clay soils. Strictly speaking, the findings of these studies are not comparable because when several variables are involved, the significance of bulk density can be masked.

An experiment specifically designed to study the effect of bulk density was reported by Foster & Martin

(1969) where the relationship between rate of erosion and 'unit weight', or bulk density, varied with slope. At a slope of 3 : 1, rate of erosion decreases with unit weight. With a slope of 1 : 1, the relationship is reversed. The interpretation was that for a given slope, there is a unique unit weight that yields a maximum rate of erosion.

Under field conditions, this relationship remains unclear. For identical degree of compaction and structural characteristics, bulk density is closely related to texture. For soils as reported in Meeuwig's (1965) study, higher bulk density should be associated with sandy soils. So there should be a positive relationship between bulk density and soil loss. For the same soil, bulk density varies with the degree of compaction. More compacted soils should have a lower infiltration rate and therefore be more erodible, chiefly by wash erosion. Yet Adams et al 's (1958) results contradict this. Many more data are required.

For organic content, Peele (1937b) found that increase in organic matter reduced the erodibility of clay soils. Browning (1937), observed that the application of organic matter to soils increased the number of large-sized aggregates for soils containing considerable quantities of either active inorganic colloidal material or organic colloidal material. Many subsequent workers endorsed the value of organic matter as a cementing material although Meeuwig (1970) suggests organic matter has an adverse effect on aggregation of sand particles. He hypothesized that the hydrophobic character of organic coating on sand particles causes the particles to resist wetting and, possibly, to possess mutual electrostatic repulsion, thus making the sand particles more easily detached and transported. Other studies mentioned above concerning water-repellent soils may also have relevance.

For other chemical properties, Wallis & Stevan (1961) determined the relation of soil chemical base status to erodibility. They found a highly significant inverse relationship between the dispersion ratio, the surface aggregation ratio, and the Ca + Mg adsorbed on the clays.

2.3 Indices of Soil Erodibility

The idea that variations in soil erodibility are related to soil physical properties and that some of these properties should logically be considered indices of soil erodibility was first developed by Bennett (1926). But it was Middleton (1930), who devised the first of these indices. He observed that the two basic physical properties affecting soil erodibility are (a) the ease with which aggregates are dispersed and (b) the rate of water transmission into the soil. On this basis, he proposed (a) the 'dispersion ratio', the ratio of the amount of silt and clay in the undispersed sample to that in sample previously treated with a dispersing agent; (b) the colloid content/moisture equivalent ratio which measures the rate of water transmission; and (c) an erosion ratio (ER) which combined the dispersion ratio (DR) and the colloid content/moisture equivalent ratio (C-M ratio),

ER = DR/C-M Ratio

The usefulness of the dispersion ratio as an index of erodibility was tested by Anderson (1951). The ratio was found to be significantly correlated with suspended sediment discharge of streams. It should be noted that suspended sediment yield is not necessarily related to soil loss unless a uniform 'delivery ratio' is assumed.

In 1954, Anderson developed another index of erodibility, the 'surface aggregation ratio' (SAR), where erodibility of a soil depends on the surface of the soil requiring binding (fine sand size and coarser) and the binding quality of the clays and

SAR ≐ SA/S+C

where SA is amount of surface on particles larger than silt size (>50μ) and S+C is percentage aggregated silt + clay. The ratio was found to be highly correlated with suspended sediment discharge from 33 watersheds in Oregon.

The surface aggregation ratio and the dispersion ratio were used as indices of erodibility in an investigation of the effect of parent material, vegetation, and climate on the erodibility of soils in north California. The surface aggregation ratio was found to be marginally more efficient than the dispersion ratio (Andre & Anderson 1961).

Yoder (1936) proposed that aggregate size in the presence of water is a relevant measure of the resistance of the soil to erosion. These water stable aggregates (WSA), are defined as the percentage of a sample which remains on a sieve of a particular mesh during wet sieving. Studying the relation between texture, structure, and erosion of residual soils of sandstone, shale, and limestone in southeastern Ohio, Gerdel (1937), observed that "the erosible properties of these soils vary with the amount, kind, and stability of the soil aggregates," implying that soil aggregation characteristics can be used to index erodibility.

Following this theory, Woodburn and Kozachyn (1956), studied soil erodibility in western Mississippi. Findings indicated a fairly good inverse relationship between percentage-weight WSA > 0.5 mm diameter and splash-loss under simulated rainfall. Adams *et al* (1958) also found a significant relationship between percentage-weight WSA > 2 mm and soil loss in his Iowa study.

Wischmeier *et al* (1958) developed a soil erodibility factor on the basis of extensive plot data collected in the United States. The factor is the average soil loss in tons per acre per unit of erosion index (EI), from a given soil in cultivated continuous fallow, with an arbitrarily selected standard plot length of 73 ft (22 m) and a 9 percent slope. Values of the erodibility factor for each of a series of benchmark soils are obtained by direct soil loss measurement. This factor will be further discussed in Section 1.6.7.

Bryan (1968b), reviewed these and other less well-known indices of erodibility. Criticisms on theoretical grounds were levelled against some of the above as 'universal' indices of erodibility : (a) the assumption that only dispersed aggregates are eroded; (b) the dependence of these indices on the percentage of silt and clay; and (c) the inclusion of 'silt' in the binding fraction. Bryan (1968b) went on to report an empirical test correlating 22 proposed indices of erodibility to soil loss under simulated rainfall and concluded that none has universal application, though indices related to aggregate size and aggregate stability were found to be more efficient than others.

Yamamoto & Anderson (1973) tested the efficiency of 16 proposed indices of erodibility using splash erosion under simulated rainfall as the standard reference. The percentage weight of WSA 0.25 - 0.5 mm in size produced the highest explained variation in a principal components analysis.

Recently, Harris (1971), following Sombroek (1966), used the idea of Middleton's dispersion ratio and developed a new index, the 'index of structure'. This index is defined as

$$(1 - NC/TC) \times 100$$

where NC is 'natural clay' and TC is 'total clay'. This index is reported on a scale of 0 to 100, with high values representing water stable materials and was found to be significantly related to porosity. A similar index was independently developed by Voronin & Kuznetsov (Nazarov 1974).

2.4 Topography

Studies in agricultural engineering have long recognized the significance of the slope factor (Bennett 1939). However, most of the experimental work in this field is confined to slopes of short length and low angle (80 m and 25 percent). Very little is known about the mechanics of erosion for steeper slopes and longer slope length. Also the difference between a 'small' plot where erosion by direct splash transportation is significant under a generally unrilled condition and a 'large' plot where erosion is dominantly by surface runoff, often in rills, has not been adequately clarified. Slope angle and slope length will be reviewed separately.

In a classical study, Horton (1945), derived a slope function which is related to erosion due to 'overland flow':

$$E_w = f(\theta) = \sin\theta / \tan^{0.3}\theta$$

where 'E_w' is amount of erosion, and 'θ' is slope angle. Reviewing a wide range of soil loss data in cultivated areas, Zingg (1940), concluded that unit area soil loss varies as the 1.4 power of the percentage slope. Musgrave (1947) suggested an average value of 1.35. Smith & Wischmeier (1957) analysed all available data in the United States and reported a best-fitting quadratic equation :

$$E_t = 0.43 + 0.30(\theta) + 0.043(\theta)^2$$

where 'E_t' is unit area soil loss and 'θ' is percent slope, All these studies are confined to slopes of less than 25 percent steepness.

Neal's (1937) laboratory study found that soil loss varies as the 0.7 power of slope in percent. The range of slope studied was 1 to 16 percent. Ekern (1954), considered the combined effects of raindrop impact and surface runoff and concluded from available literature that erosivity of storms should be a function of slope to the power 1.0. Schumm (1956), conducted a laboratory study in which very steep slopes (up to 60°) were considered. He found a very good positive relationship between erosion of one of his Perth Amboy badland samples and the sine of the slope. Apparently, splash erosion was negligible.

In a laboratory study of 'small' plots, Ekern (1950) presented a derivation of the theoretical relationship between slope (θ) in degrees and percentage of total splash loss in the downslope direction (Sp) :

$$Sp = 50 + \sin\theta \times 100$$

for a slope range 0 to 30 degrees. This relationship accords well with empirical data. However, the percentage of splash loss in the downslope direction should be distinguished from total splash which Ekern did not comment upon. Rowlison & Martin (1971), suggested in their 'Rational Model' that impact force and therefore detachment rate by raindrop impact decreases with increasing slope because the normal component of the impact force is a function of the cosine of the slope. On the other hand, transportation rate due to raindrop impact increases with slope because the tangential component of the impact force increases as the sine of the slope. Under the laboratory conditions considered, (i.e. 'small' plot) amount of soil loss due to runoff water is small for shallow depth of flow. Because maximum erosion can be either detaching capacity limited or transportation capacity limited (Ellison 1947), the arguments presented would imply a non-linear relationship between slope and splash loss.

Both Shvebs (1968) and Lattanzi *et al* (1974) measured splash loss (E_S) under varying laboratory conditions. Shvebs collected splashed particles both up and down slope and found that 'E_S' is a direct function of slope for a range of 1 to 20 percent slope.

Lattanzi *et al* (1974) collected splashed particles only at the lower end of the plot. Therefore, although amount of splash shows an increase with slope, the result cannot be compared to other studies. For study of slope length, Horton (1945) thought that a 'belt of no erosion' exists at the upper end of a given slope because within this belt both velocity and depth of overland flow are insufficient to produce detaching forces large enough to remove soil particles. Recently, Yair (1974), among others, has questioned the whole idea of a 'belt of no erosion'. Meyer & Monke (1965), observed that the regression line of soil loss on slope length showed a negative intercept for soil loss in a laboratory experiment using spherical glass beads in the non- cohesive sand size range. This result suggests erosion will only occur beyond a threshold slope length but this can only be true if there is no raindrop splash.

In cultivated areas, Zingg (1940) found that soil loss per unit area varies as the 0.6 power of slope length. Musgrave (1947) proposed a value of 0.35. Wischmeier et al (1958), summarized previous work and suggested that the exponent is variable from year to year. For field use a value of 0.5 ± 0.1 was suggested.

For badland slopes, Schumm's (1956, 1964) data as presented in Carson & Kirkby (1972) show that erosion varies with the 0.77 power of slope distance from divide in Perth Amboy, and 1.0 power in western Colorado.

2.5 Rainfall

In the study of rainfall erosion, rainfall characteristics are of fundamental importance. The major work depicting the relationship among various rainfall characteristics was done by Laws (1940, 1941) and Laws & Parsons (1943). They found that the median drop size (D) in mm is related to rainfall intensity (I) in in/hr in the equation

$$D_{50} = 2.23\ I^{0.182}$$

with maximum intensity of 4.5 in/hr (11.4 cm/hr).

Later, Best (1950) presented a different exponent for the same relationship :

$$D_{50} \propto I^{0.232}$$

Still later work (Blanchard 1953, Rogers et al 1967) demonstrated that during a given storm drop-size frequency distributions vary even if intensity remains constant.

The concept of the existence of a definite relationship between rainfall energy and soil loss with special reference to rain splash was first explicitly stated by Laws (1940) :

> "The key to a possible solution of this problem lies in viewing the phenomenon of erosion as a purely mechanical process. When soil is moved, mechanical work is done. What is the source of the energy for this work ? Certainly part of it is derived from the kinetic energy of the falling raindrops. This immediately suggests that there may be some correlation between the energy expended by the rain and the resulting soil loss." (p. 432)

Wischmeier & Smith (1958) found a highly significant relationship between rainfall energy (E) and intensity (I):

$$E_K = 916 + 331 \log (I)$$

where E_K is in ft-ton/acre-inch and I is in in/hr. This relationship was extrapolated to beyond 6 in/hr (15.2 cm/hr) intensity. A conversion table from rainfall intensity to kinetic energy was presented. It was noted that such a relationship would not apply to 'orographic' types of rainfall.

However, Hudson (1963) demonstrated that for high intensity rainfall (above 4.5 in/hr, or 11.4 cm/hr), the relationship between drop size and intensity does not hold. For tropical rainfall, median drop size actually decreases with increasing rainfall intensity beyond 4.5 in/hr. Therefore the type of relationship established by Laws & Parsons (1943) and Best (1950) cannot be extrapolated.

Smith & Wischmeier (1962) later observed that there was an over-estimation of the kinetic energy by the above equation for the highest intensities, as was evidenced by the data of Hudson (1963) and Mihara (1951).

In a study of drop size data from Miami, Kinnell (1973) shows the variations in the relationships between rainfall parameters (momentum, kinetic energy and kinetic energy per unit horizontal area of the drop) and intensity between rain types and geographic locations. Given the relatively large amount of variations in relative drop size distributions within any rain types, he questioned the applicability of values obtained for a parameter from one location to another. Based on similar observations on raindrop size distributions, Rogers et al (1967) concluded that kinetic energy calculated from intensity measurements for individual storms may be erroneous. However, such errors would likely diminish in importance in any consideration of seasonal rainstorm kinetic energy values.

The situation when a thin layer of water is present introduces another variable : the thickness of this water layer. Palmer (1963, 1965) noted the critical depth of water layer (depth at which the maximum impact force is achieved) for the 2.9-mm diameter drop is 2.0 mm, for the 4.7-mm drop, 4.0 mm, and for the 5.9-mm diameter drop, 6 mm. This implies that maximum rainfall erosivity occurs in the region where the critical depth has a near 1 : 1 relationship with the horizontal drop diameter on impact.

Many experiments have been conducted relating various rainfall characteristics to soil loss. For splash erosion, Ellison (1945) developed an empirical equation relating amount of splashed Muskingum silt loam (E_s), to drop velocity (V_d), drop size (D), and rainfall intensity (I) :

$$E_s = K\, V_d^{4\cdot 33}\, D^{1\cdot 07}\, I^{0\cdot 65}$$

where 'K' denotes variations in soil properties. Using standard sand, Ekern & Muckenhirn (19'7) found that the amount of splash is related to both intensity and drop size, and suggest a critical drop diameter below which there is no erosion. Later, Ekern (1950) used energy per unit area to characterize rainfall erosivity. There is a linear relationship between amount of splash and energy per unit area. Again, a critical energy unit is implied in the relationship established. An experiment similar to that of Ellison (1945) but using standard sand was conducted by Bisal (1960). The empirical relationship established was :

$$E_s = K\ D \cdot V_d^{1.4}$$

where E_s is splash, D is drop size, V_d is drop velocity and K is an empirical constant. Rainfall intensity was not found to be significantly related to the amount of splash erosion.

For total soil loss (splash + wash loss, E_t) Neal (1937) found that

$$E_t \propto I^{1.20}$$

for Putnam Silt loam surface soil under laboratory experimental conditions. Wischmeier & Smith (1958), examined various combinations of rainfall parameters affecting soil loss and concluded that the product of 'total kinetic energy' and 'maximum 30-min intensity' is the most significant variable affecting soil loss.

Observing that there is little or no erosion at low intensities, Hudson (1971) in Rhodesia found by discarding rainfall intensity of less than 2.5 mm/hr in the computation of 'EI' values, an excellent correlation between rainfall energy and soil loss. This holds for (a) splash of standard sand from Ellison-type splash cups; (b) soil loss from small field plots of 100 x 30 cm using a sieved clay loam soil maintained at constant moisture status; and (c) soil loss from larger field plots of 27.5 x 1.5 m where undisturbed soil was used and soil moisture content was uncontrolled.

2.6 Vegetation Cover

The major influence of vegetation cover is its protective effect on the soil from direct raindrop impact, promoting high rates of infiltration, and resistance to overland flow.

Wollny pioneered the study of the effect of plant cover on soil loss (Baver 1938), showing that the percentage of total rainfall penetrating the vegetative canopy varies with the type of crop. For protected soils, the non-capillary porosity was 34 - 53 percent higher than unprotected soils.

Following Wollny, many investigations concerning the relationship of type of crop and management of soil loss were carried out. These data were collated and the major relationships summarized by Wischmeier (1962).

The work of Borst & Woodburn (1942) was one of the earliest studies in North America concerning the effect of mulching on soil loss. They found that for simulated rainfall in the field,

> "interference with overland flow when plots were surface mulched was not of great

> importance in curtailing soil loss. Elimination of rain-drop impact, with its destructive effect on the soil surface, rather than the reduction of overland flow velocity, appeared to be the major contribution of the mulch." (p. 21)

For the quantitative relationship between soil loss and cover, generally consistent results were obtained by a number of rangeland scientists. For coarse sand derived from granite in Idaho, Packer (1951) found soil loss strongly related to the size of maximum bare openings and ground cover density. Rate of increase in soil loss is low for decrease in cover density from 100 to about 70 percent.

Osborn (1954b), investigated the effectiveness of cover in reducing soil splash by raindrop impact. Detachability of bare soil was measured under simulated rainfall and the results extrapolated to field plots of size 32.8 x 49.2 cm. This calculated splash value (S_c) was used to compute splash effectiveness (SE),

$$SE = (S_c - E_s)/S_c$$

where E_s is measured splash under simulated rainfall with cover in the field. Measured cover density and bulk weight of vegetation were found to be significantly correlated with SE.

For silty clay loams derived from limestone and shales in subalpine central Utah, Meeuwig (1965) found that the variables : protective cover (which is defined as plant cover + litter + stone) and soil bulk density explained 81 percent of the variation in eroded soil. Meeuwig (1970) later confirmed the significance of cover to soil loss in the middle-to-high elevation herbaceous rangelands of western United States.

These field studies show a negative exponential relationship between relative amount of soil loss and percentage cover.[2] The work on splash erosion by Osborn (1954b) shows a similar pattern. However, similarly plotted data presented in Shvebs (1968) indicates much slower rate of increase in soil loss with cover less than 50 percent. Apparently under the laboratory simulation conditions when finely chopped straw was used the small amount of mulch tends to be covered by a thin layer of water. According to Palmer (1965), such a layer increases turbidity of water and tends to offset the effect of mulching to some degree. But when the surface coverage by the mulch is more than 50 percent, this effect becomes insignificant and the protective role of the mulch increases rapidly.

Kramer & Meyer (1969), studied the effect of surface mulching on soil loss and runoff velocity on a number of slopes. Two sizes of glass spheres, averaging 33 and 121 microns, were used in the laboratory experiments. Generally a relatively small mulch rate (about 1-2 m-tons/hectare) greatly reduced the erosion rate and runoff velocity for the range of degrees and lengths of slopes studied. However, for the 33-micron spheres, small mulch rates (0.25 to 0.5 m-tons/hectare) significantly increased erosion rates for the longer slope lengths. This result basically demonstrates the greater erodibility of the smaller spheres but apparently the mulch stems lying on the soil surface increases surface roughness and thus the velocity and turbulence of the runoff. Also the same kind of thin water layer effect found in Shvebs (1968) experiments may apply. Such a possibility is suggested by Meyer et al (1970).

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[2] i.e. Very rapid increase in soil loss with cover smaller than 70 percent.

Results obtained by Lattanzi et al (1974) indicate that mulch is highly effective in reducing soil loss from interrill areas. Mulching reduces the amount of bare soil exposed to rainfall detachment; restricts the movement of soil by splash; reduces the average flow velocity and thus decreases the amount of runoff. However, mulching may be much less effective in controlling soil loss where rills may develop beneath the mulch or mulch may be removed by flow.

2.7 Soil Loss Prediction Equation

Early attempts in developing a prediction equation include those of Zingg (1940), Musgrave (1947), and Van Doren & Bartelli (1956). Wischmeier & Smith (1961) collated 8 250 plot-year records from extensive agricultural areas east of the Rockies in the United States and developed the now well-known Universal Soil Loss Equation (USLE).

In this equation, 'long-term' soil loss (A) is expressed as a function of the following factors : rainfall factor (R), soil erodibility factor (K), slope length factor (L), slope angle factor (S), cropping management factor (C), and erosion-control practice factor (P), so that

$$A = RKLSCP$$

Details of evaluation of each factor are available from a USDA handbook (Wischmeier & Smith 1965). Minor updating of this prediction procedure with nomographs has been presented (Wischmeier et al 1971).

Since this Equation was developed from data in cultivated areas, extension into unfarmed watersheds require considerable modification. Wischmeier (1971) attempted to modify factor 'C' in the equation to non-cultivated land. Williams & Berndt (1972) demonstrated possible forms of modification of the Equation in the Texas black prairie area. Short-cut formulae for estimation of factor 'R' from readily available rainfall data were developed (Ateshian 1974).

Beyond the areas from which the Equation was developed, modification is much more difficult because very little is known about the interplay of the controlling factors in rainfall erosion. Farmer & Van Haveren (1971) suggested that the relationship between rainfall intensity and kinetic energy assumed in the Equation is unlikely to apply to the Intermountain Region.

In the Canadian Prairies, Wigham & Stolle (1973) found that additional factors such as effective drainage area need be considered in attempting to apply the USLE to the areas. Their results indicate a good agreement between predicted soil loss and measured sediment yield. However the study omits any consideration of sediment delivery ratio.

Most recent developments in this field include the erection of 'first-generation' mathematical models to simulate the process of water erosion.

Following Ellison's (1947) idea, a conceptual model which considers four separate but interrelated phases was proposed. These include : (a) soil detachment by rainfall, (b) transport by rainfall, (c) detachment by runoff, and (d) transport by runoff (Meyer & Wischmeier 1969). Mathematical submodels for each part of the erosion process were developed, and pertinent parameter values were approximated from available information on basic relationships. The submodels were then combined in a computer program to route the soil downslope,

Forster & Meyer (1972) proceeded further. They attempted to describe water erosion on upland areas by the continuity of mass transport equation and an equation expressing an interrelationship between detachment by runoff and sediment load.

Considering the number of assumptions involved in the model and their restrictions in application to field situations at the present 'state of the art', a great amount of research work and data will be required to implement a more flexible mathematical erosion model.

2.8 Summary

Although this survey is not exhaustive, it reveals the difficulties involved in establishing comparability of results because of variations in experimental techniques. However, even if measurement techniques can be standardized as in the USLE, the applicability of these results over larger areas is of questionable value. Differences in rainfall characteristics over areas of high relief is a case in point; but even subtle changes in any number of soil characteristics are likely to produce considerable variations in measurement results.

CHAPTER THREE

PHYSICAL BACKGROUND OF STUDY AREA

3.1 Introduction

The watersheds under study lie in three physiographically distinct zones : mountains, foothills, and plains. Commonly known physical characteristics of the three zones (e.g. Hardy 1967) generally apply to these watersheds. These are described with special reference to the selected basins in Sections 3.2 - 3.7. Further details concerning the selected units are presented in Sections 3.8 - 3.11.

3.2 Bedrock Geology

Sedimentary rock formations from the Cambrian to the Cretaceous age outcrop in the study area (McCrossan & Glaister 1964). Generally, three rock groups, each differing in their relative resistance to erosion, can be recognized : Palaeozoic limestones & dolomites, Mesozoic and Tertiary shales, and Mesozoic & Tertiary sandstones & conglomerates (Fig. 3-1). Strong compressive forces from the west in Tertiary times produced folding, thrusting and faulting in the western part of the area where the Rocky Mountains are located. The dominant structural trend of the mountain system is N 20° W.

At the same time, fault blocks of Palaeozoic limestones & dolomites were thrust eastwards on to Mesozoic strata. The Highwood Range is a typical example (Hage 1943). A major synclinal valley subsequently developed, the axis of which is located in the present day upper Highwood River valley (Allan & Carr 1947). The valley is flanked by Palaeozoic limestones & dolomites which form the continental divide in the west and the Front Ranges in the east. The main valley of the Cataract Creek Basin is the southward continuation of this intermountain valley (Fig. 3-1).

Folding and faulting, however, is not confined to the mountains. Faults are numerous in the foothills where the less resistant Mesozoic strata responded to stress by rupture (Beach 1943). Subsequent erosion produced parallel sandstone and conglomerate-capped ridges and shale valleys (Hage 1943, Beach 1943).

Within the plains, bedrock is progressively older towards the east as these younger formations were marginally affected by mountain building and only minor warping occurred. The rock formations represented are upper Cretaceous and Palaeocene sandstones.

Total uplift of the area is contemporaneous with mountain building in the west. Upland surfaces in the plains[1] capped by the Paskapoo Formation in the northeast corner of the area may be remnants of at least two Tertiary plain levels (Russell 1957).

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[1] e.g. the Wintering Hills

3.3 Glacial Geology, Geomorphology, & Landforms

Although the major topographic patterns of the area were set prior to the Pleistocene, it was the Pleistocene glaciers that are largely responsible for the details of the present-day landforms. In North America, many glacial periods are thought to have existed in late Cenozoic times (Flint 1971). Rutter (1966) postulated four Cordilleran ice advances in the Bow Valley. Shaw (1972) indicated that intervalley correlations show no consistent sequences after the major advance.[2]

The area was affected by both the Continental ice sheet from the north and northeast, and the Cordilleran ice from the west (Stalker 1957). In the mountains, alpine glaciation produced distinctive erosional features such as cirques and U-shaped valleys. Allan & Carr (1974) suggested that the upper limit of valley glaciation in the mountains is not likely to be much higher than 2 300 m. Striations and flutings are observed in numerous locations in the foothills and the mountains.

East of the mountains are extensive glacial deposits including superposed tills of distinctly different origins[3] but it is still unclear whether there was any coalescence of the two glaciers. Stalker (1956) suggested the foothills erratics train provides the evidence for this coalescence but Alley (1972) and many others postulate that the mountain glacier receded considerably prior to the advance of the Laurentide ice sheet.

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[2] This is probably dated at less than 11 000 years B.P. (Harris & Boydell 1972).

During the last major advance, the maximum extent of the Laurentide ice sheet was west of the Porcupine Hills, approximately following the 5,000 ft (1 524 m) contour (Alley 1972). Seagel (1971) postulated this maximum extent to be along the ridge northeast of Priddis Creek. An unpublished Alberta Soil Survey map[4] indicates that the Stimson Creek-Chain Lakes line approximates this boundary.

The last major Laurentide ice sheet advanced from the north between 25 000 and 14 000 years B.P. As a result of the regional slope, it blocked the drainage from the west and produced proglacial lakes west of the ice sheet. Retreat of the ice sheet during deglaciation formed similar lakes to the east (Harris & Boydell 1972). Proglacial lakes were located west of the Porcupine Hills (Douglas 1950). Extensive lake deposits are also found along the foothills-plains margin, notably in the lower Three Point Creek Basin northwest of Turner Valley and the general Turner Valley-Black Diamond area. They also occur at lower levels, in the northern part of that basin. These varying phases of laking in the Pleistocene may be related to deltaic deposits as far up the major drainage channels as the upper Highwood, near Cat Creek (Allan & Carr 1947).

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[3] The cordilleran and Laurentide tills are generally distinguished by lithology of incorporated stones (Jeffrey et al 1968, Alley 1972), relative amounts of montmorillonite and illite (Tharin 1960, Pawluk & Bayrock 1969), and carbonate content (Pawluk & Bayrock 1969, Twardy et al 1974)

[4] Unpublished data for 1 : 250 000 Map Sheet 82-G & 82-J outside the Forest Reserve

During glacial retreat, varying amounts of outwash were deposited in major channels and spillways. Subsequent downcutting into these deposits[5] produced terraces in these valleys. Laycock (1957b) recognized seven levels within a range of 120 m in the Sheep and Allan & Carr (1947) found six levels in the Highwood. Two of the latter are traceable for a considerable distance along the valley.

Also during Laurentide ice retreat, isolated dead ice produced a hummocky moraine topography that is typical of large areas in the plains (Gravenor 1955, Gravenor & Kupsch 1959, Stalker 1965). Areas immediately southwest of the Bassano Dam and north of Gleichen show the typical knob-and-kettle topography (Fig. 1-2). Eolian deposits are scarce and occur only in small localities in the plains, such as east of Vulcan.

The topography thus developed changes distinctly from the mountains to the plains. Each is characterized by a distinct suite of landforms. However, within-zone variations are considerable and the landforms are best described with reference to the selected drainage basins. Table 3-1 summarises the basic morphometric properties of the basins.

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[5] In other cases tills and alluvial deposits

The changes in mean ground slope and relative relief with elevation for the three zones are well illustrated by these data. Drainage density of these basins are not available but data from air-photo analysis in the Highwood River Basin indicate a general reduction in drainage density with decrease in elevation.[6] This is compatible with basic morphometric laws that relief and slope increases with drainage density (Horton 1945, Schumm 1956). The observed range of density is 13.7 to 24.2 km/km² in the mountains and upper foothills. This is considerably higher than a range of 8.9 to 14.5 km/km² found in the West Arrowwood Creek area on the plains. The general landform characteristics in the area within each selected basin will now be considered separately.

3.3.1 Cataract Creek Basin

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[6] Drainage density was determined by the following method. Four circles of radius 2.5 cm were drawn at the center of each quarter of a 23 x 23 cm transparency sheet. The sheet was placed on alternate photographs of selected strips. Drainage lines were then marked in the circles on the sheet and the total length measured. Photograph coverages were transferred to topographical maps (scale 1:250 000) and the areas of the circles were calculated from the map scale.

Cataract Creek lies within the western part of the intermountain zone. The continental divide forms the western water divide of the basin where outcrops of Palaeozoic limestones and dolomites produce relatively resistant colluvial deposits at the bases of these lofty east-facing slopes. However, there is an absence of modern glacier fields along the divide. Outcrops of Mesozoic sandstones between Wilkinson and Cummings Creek produce only small colluvial deposits in the eastern part of the basin.

Deposition of glacial till is extensive in the basin especially in the western section (Fig. 3-2a). This is reflected in the general decrease in mean ground slope and relative relief from east to west (except for the continental divide). Many of these deposits are relatively thin and intermixed with varying amounts of colluvium. Some outwash and alluvial deposits are found along the major channels which are often flanked by narrow benches of discontinuous terraces. Many sections of the Creek are cut into bedrock and there is a general absence of braided channels except where the Creek cuts across a major sandstone ridge east of Wilkinson Creek.

3.3.2 Pekisko & Stimson Creek Basin

Pekisko Creek Basin is located immediately east of Cataract basin and its upper reaches originate from the steep eastern slopes of the Highwood-Livingstone Range, 2 540 m high at Mt Burke. Stimson Creek Basin is located to the southeast and except for the absence of a steep upper reach, it is very similar in practically every aspect to the Pekisko Basin.

The dominant regional geomorphological features are the development of parallel sandstone ridges separated by shale valleys that are often thickly mantled by various types of surficial deposits. These higher sandstone ridges often bear linear elements that evidence glacial erosion. Towards the west, U-shaped valleys flanked by precipitous rocky slopes are characteristic. Extensive glacial, glacio-fluvial and lacustrine deposits are found in the eastern part of the basins. Thus gentler slopes and lower relative relief are dominant. These deposits (mainly glacial till) mantle many prominent terrace levels in the Pekisko Creek Basin. At least three levels can be recognized, of which the uppermost is distinctive in its hummocky appearance (Plate 3-1). Because the deposits are relatively thick, bedrock exposure along major channels are limited to the upper reaches.

3.3.3 Three Point Creek Basin

Three Point Creek is located further to the north where the foothills zone is considerably broader. The Creek originates from the steep eastern slopes of the Front Range, the highest point of which is Three Point Mountain at

2 595 m. The upper part of the basin is well within the Forest Reserve and is typified by high relief and steep slopes. Possibly because of the nature of this topography, distribution of glacial deposits is much more retricted than elsewhere in the foothills zone. Relatively large tracts of outwash and alluvial deposits are found where Volcanic Creek joins the main Creek, at upper Death Creek valley, and along the main Creek where the Ranger Station is located (Fig. 3-2c).

In the lower part of the basin, the valley is considerably wider and flights of terraces are better developed. They are found on till deposits which have undergone a variable amount of fluvial reworking (Peters & Bowser 1960). At least two major levels can be recognized around the Charmes Section (Plate 3-2). Bedrock exposures along the main Creek are uncommon in this part of the basin and some evidence of braiding in the channel is found below the confluence of Ware Creek and the main Creek.

3.3.4 West Arrowwood Creek Basin

From the summit of a conical hill that rises to about 1 130 m west of the East Arrowwood to the bottom of the West Arrowwood Creek valley, is found an area of relatively high relief and steep slope : a relief of about 170 m and a ground slope of 30 to 45 percent. However, except perhaps for the northwest section, relief is low and slopes are elsewhere very gentle. The presence of a steeper lower section is distinctive of West Arrowwood Creek Basin among prairie watersheds. Also distinctive of the basin is that it includes comparatively small areas of knob-and-kettle topography. Practically the entire basin is mantled by glacial and glacial-fluvial deposits which have undergone a variable amount of reworking by water action. The main channel is entrenched into this plain surface north of Herronton but mainly surficial deposits are exposed.

3.4 Soils

Soils of the study area are largely developed from glacial, glacial-fluvial, and glacio-lacustrine deposits, although residual soils are also represented. In the plains and most of the foothills, soil information is available from Alberta Soil Survey Reports (Wyatt & Newton 1925, Peters & Bowser 1960). In the mountains and upper foothills, Laycock (1957b) mapped the soils within the Forest Reserve according to a physiographic classification. Other informations are available only for relatively small areas.[7]

In the prairies, Chernozemic soils developed largely from Laurentide till are present. They range from dark brown in the southeast to black soil in the west. Profile development and range of texture is related to variations in type of parent material which has undergone varying degrees of reworking by water and wind. Almost the entire West Arrowwood Creek Basin is within the dark brown soil zone. According to parent material, four major types of soil can be recognized (Fig. 3-2d). They include resorted glacial, resorted residual, alluvial, and eolian and alluvial types (Peters & Bowser 1960). Soils are generally loamy, with varying amounts of stones present.

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[7] Crossley 1951, Jeffrey *et al* 1968, Beke 1969, Pettapiece 1971, Kakanis 1972, Mee 1972.

In the foothills, the pattern is complex. The lower foothills zone still has zonal soils ranging from dark brown to thin black to black but increasing areas of dark grey to grey-wooded soils are found further west. Brunisolic and Regosolic soils are also developed. This greater complexity can be related to influences of topography and aspect (Mee 1972). Profile development is very variable.

In the lower Three Point Creek basin, mainly black soils are represented (Fig. 3-2c). According to parent material, four soil types are found : light clay residual soil developed from shale; clay loam to heavy loam from calcareous (?) till; light clay from glacio-lacustrine deposits; and loam from alluvium (Peters & Bowser 1960). But unpublished data from Alberta Soil Survey shows the dominance of black Chernozem in the south and the southeast (Fig. 3-2b). Thin black soil is found only along the main ridge running along the eastern boundary of Stimson Creek

Basin. Grey-wooded soils occur towards the higher levels.

With relatively higher precipitation excess, podzolization is the major soil-forming process in the mountain areas. Soils in these areas show a dominance of Podzols, Luvisols, and Brunisols. On Alpine meadows, mountain chernozems may be found. Jeffrey _et al_ (1968) studied the watersheds of the Upper Oldman River which is immediately south of Cataract Creek Basin. They cited a topo-sequence: Regosol, Eutric Brunisol, Luvisol, Brunisolic Luvisol, and Bisequa Grey-wooded on calcareous parent material; and another sequence : Regosol, Dystric Brunisol, Podzol, and Gleyed Podzol on non-calcareous parent material. The same probably applies to Cataract Creek proper. Profile development, however, is generally restricted.

3.5 Vegetation & Land Use

The natural vegetation of the area is dominated by prairie grassland in the east and woodland in the foothills and mountains. The 'parkland' forms a grassland-woodland ecotone between these two areas. Actual distribution of parkland vegetation is confined to the area south of Calgary and west of High River, immediately east of the foothills (Rowe 1972).

The climax vegetation in the prairies is thought to be rough fescue (_Festuca scabrella_), spear grass and grama grass (_Stipa-Bouteloua_) (Moss 1955). The western boundary of this zone is indistinct and is marked by a fringe of trembling aspen (Populus tremuloides) groveland.

Foothills vegetation is dominated by mixed deciduous-coniferous woodland : aspen (Populus tremuloides), and lodgepole pine (Pinus contorta var. Latifolia) (Rowe 1972). Aspen-poplar and some rough fescue are found in the outer foothills and lodgepole pine is the dominant species in the inner foothills (Moss 1955).

In the mountains, the spruce-fir association (Picea Engelmanni-Abies lasiocarpa) and lodgepole pine are dominant (Boag & Evans 1967, Rowe 1972). The timber line stands at about 2 100 m.

Most of the grassland in the plains and part of the lower foothills has been brought under cultivation either presently or at one time. Wheat, barley, oats, rapeseed and flax are the main crops in the prairies whilst hay crops and other forage crops are common in the lower foothills. A considerable area of the foothills has been and is used for grazing purposes. Past and present clearings are evident.

Over 90 percent of West Arrowwood Creek basin is presently under cultivation (Table 3-2), a factor that may have some effect on sediment yields in the area. This will be discussed later. Outside the Forest Reserve, Three Point Creek basin has 25 percent of its area under cultivation, 19 percent under grass, and 59 percent wooded. On the other hand, Pekisko and Stimson together has 10 percent under cultivation, 60 percent under grass, and 30 percent wooded.[8] Inside the reserve, except for some alpine meadows and barren areas with thin soils above the timber line, most of the watersheds are well protected by dominantly coniferous trees.[9]

The mountain areas are totally within the Reserve. Other than isolated areas where logging or forest fires had taken place, a good forest cover has been maintained. This is true of the Cataract Creek basin in general.

However, Hanson (1951) reported that within the Forest Reserve from the 49th parallel to the Bow, about 25 000 cattle and 2 500 sheep were grazed during the summer months. It appears that this practice is continuing in the Reserve.[10]

3.6 Climate

Climate of the area is of a subhumid continental type in the foothills and plains with warm summers and cold winters. The mountain areas show very marked variation in climate with altitude.

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[8] Data estimated from A.R.D.A. Land Use Maps.
[9] Composite Forest Series, Dept. of Lands & Forest, Alberta
[10] Eastern Rockies Forest Conservation Board, Annual Report, 1972-73.

3.6.1 Temperature

In general summer mean temperatures decrease from the plains to the mountains but in winter mean temperature decreases in the opposite direction. Mean monthly temperatures of selected stations in the area are presented in Fig. 3-3 and Table 3-3. Their locations are shown in Fig. 1-4. Since most established mountain stations in the area (e.g. Lake Louise) are in valley locations, they are not representative of extensive mountain slopes in the area. Adjusted data of Kananaskis LO is thus included to demonstrate the difference in temperature due to variations in topographic position.

The number of freeze-thaw cycles experienced in the area is in the range of 60 to 80 per year. It generally increases from no[illegible] to south. At Lethbridge, an average of 76 freeze-thaw cycles per year with peak frequencies in April and November was noted (Fraser 1959).

Soil temperature usually lags behind air temperature so that although mean temperatures are above 0° C in April at all stations, soil temperatutes even in day-time could still be below freezing point.[11]

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[11] This would in fact form an impervious sublayer during snowmelt and likely increase the proportion of runoff than otherwise if the sublayer is not present.

3.6.2 Precipitation

Mean annual precipitation increases from about 375 mm in the plains to well over 700 mm in the mountains (Laycock 1957a, Longley 1972). However, variations in the mountain areas are much larger because of orographic and aspect effects. The pattern of mean summer rainfall is essentially the same. Precipitation amounts for selected stations in the area are presented in Fig. 3-4.

There is generally a rapid rise in precipitation in the area during the spring to a maximum in June and then a sudden drop in July. But the proportion of precipitation in snow tends to increase towards the mountains. Also the snow season tends to be longer in the west. Thus, on the average, the snowmelt period of the prairies comes in late March or early April but in the mountains it can come as late as late June (Longley 1972). The average time for snowmelt in the foothills lies somewhere between these two extremes.

Being frontal in nature, spring and early summer storms in the area are usually extensive in nature. But in mid-summer, storms tend to be related to local convectional currents and therefore are usually localized. Precipitation rate (mainly rainfall) associated with these storms tend to be higher.

3.6.3 Rainfall Intensity

For shorter durations, rainfall intensity data are available for only a few localities in the area.[12] For the stations of Calgary A, Vauxhall, and Lethbridge A, intensity-frequency curves were constructed (Fig. 3-5).[13] The station of Edmonton A is included for comparative purposes. For 15 and 30-min rainfall for a return period of 2 years, 1.55 in/hr and 0.97 in/hr (39 mm/hr and 25 mm/hr) are registered at Calgary A. These are the highest intensities compared to the other two south Alberta stations. For the same duration but for a return period of 25 years, Lethbridge has the highest intensity (4.1 in/hr and 2.5 in/hr, or 104 mm/hr and 64 mm/hr). Vauxhall, lying to the east of the first two stations, shows the lowest intensity in all cases.

Data for the experimental watersheds : Marmot Creek and Streeter Creek (Fig. 1-1) record only storms of an intensity greater than 0.5 inches (12.7 mm) in 24 hours[14] and therefore an intensity-duration analysis cannot be performed. Rather the percentage of records exceeding threshold values of a given duration were computed for the three stations where data are available.[15] A similar computation was performed for the other stations : Calgary A, Lethbridge A, and Vauxhall, but in these latter cases all available data on maximum intensity[16] in a given month is used without any attempt to single out storms of greater than 0.5 inches (12.7 mm) per 24 hours. Therefore the computed percentages tend to be lower than the first group of stations. Also some data are available from the stations at Kananaskis and Highwood Pass collected by the Alberta Forestry Service. These computed statistics are presented in Table 3-4.

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[12] Bruce (1968) produced maps showing variations in short-duration rainfall intensity but these are only based on a few stations in the whole area, generally following the maximum one-day rainfall pattern.

[13] Analysis data available from Mr V. K spliak, Atmospheric Environment Service, Canada Dept. of Environment, Edmonton Office.

Despite the limited records available and the crude method of comparison, the data clearly show that the foothills locations tend to get the highest intensities. Intensities are apparently lower in the prairies and much lower in the mountain areas. This finding is basically consistent with the storm potential pattern (McKay 1964) and the 24-hr intensity pattern (Bruce 1968). Also such a pattern is consistent with the type of rainfall observed in these areas.

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[14] Data published in Compilation of Hydrometeorological Record, Marmot Creek Basin, Vol. 1 to Vol. 9, and Compilation of Hydrometeorological Record, Streeter Basin, Vol. 1 to Vol. 9. They are made available by D.L. Golding, Research Scientist, Northern Forest Research Centre, Canadian Forestry Service, Edmonton

[15] Marmot Creek CON 4 & CON 5; Streeter Creek Site 7

[16] Data published in Monthly Record, Meteorological Observations in Canada, Atmospheric Environment Service, Canada Dept. of Environment, Toronto, 1961-1973

Rainfall in the area is either related to northeasterlies associated with the incidence of cold lows in May and June (Reinelt 1970), or a result of local convectional activity. This latter pattern produces isolated storms of relatively high intensity and short duration, mainly in July and August (Longley 1972).

Whilst summer convectional activities tend to be localized and therefore in the long run may not show any prominent regional variation, 'deep upslope' rainfall is strongly influenced by orographic effects and could produce relatively high-intensity rainfall showing distinctive spatial patterns. Reinelt (1970) estimated the orographic effect on total precipitation to be about 40 percent over a similar area without topographic influence. Since this type of rainfall makes up about 45 percent of the total of Southwest Alberta, it would be reasonable to assume that rainfall intensity is highest on the upper foothills below the Front Range. Topographic effect tends to lessen towards the east and therefore rainfall generally decreases in this direction. In the intermountain area beyond the Front Range, orographic effects are absent, and although total precipitation may be high as a result of spillover snow from the west (Laycock 1957b), rainfall intensities in these areas are generally low.

3.7 Hydrology

Actual evapotranspiration data in the area are very limited. Using the Thornthwaite approach, Laycock (1957a) studied the variations in potential evapotranspiration within the Forest Reserve. Average annual potential evapotranspiration decreases from the plains to the mountains, mainly because of temperature differences. Water balance diagrams showing seasonal variations in potential and actual evapotranspiration, surplus and deficit patterns are shown in Table 3-5 and Fig. 3-6.[17]

The general trend is for surplus to increase from the plains and lower foothills to the mountains. However, the intermountain areas show a lower surplus. Deficit is high in the plains but is low in the upper foothills. Intermountain areas show high deficits.

The timing of the deficit pattern also shows considerable variation. The plains areas tend to have a longer deficit period, mainly from early July to late October. In the foothills and mountains, the deficit period is shorter, probably much shorter than the data suggest because the snowmelt event is likely to be much longer than assumed by the Thornthwaite procedure.

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[17] Computed according to the Thornthwaite procedure (Thornthwaite & Mather 1957).

3.7.2 Water Yield

Laycock (1957a) indicates a general increase in yield (surplus) from the plains westwards. Actual surface water data reported by Water Survey of Canada[18] and analysed by McPherson (1975) were plotted against elevation in Fig. 3-7.

This figure demonstrates the effect of regional topography on precipitation and water yield. Presumably the effect of vegetation cover is also included. It should also be noted in this relation that extensive areas in the plains and parts of lower foothills do not contribute to streamflow in a normal year because of the presence of areas of 'internal' drainage. In actual fact, the drainage area of these basins varies from year to year, depending on the size of the runoff event (Stichling & Blackwell 1957).

Flow regimes show again a marked variation. The major hydrologic event in the prairies and lower foothills is the April snowmelt. In normal years this will be the peak discharge period (Fig. 3-8). Only very heavy and extensive rainfall in late summer will give a secondary peak later in the wet season.

In the mountains and upper foothills, spring thaw occurs in May or June. This may coincide with late spring-early summer rain to produce a prominent flow peak (Fig. 3-8b to 3-8c). For major rivers that flow across these regions, such as the Bow, peaking as a response to different snowmelt periods of the plains and mountains would be expected (Fig. 3-8f).

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[18] Data for varying periods from 5 to 30 years

3.7.3 Sediment Yield

The regional pattern of sediment yield was reported by Stichling (1973). From large basin data, the average yield is 17.5 to 87.5 m-tons/km²/yr. Hollingshead, Yaremko, & Neill (1973) cited sediment yield data for basins ranging in size from 163 to 116 500 km². A yield range of 47 to 84 m-tons/km²/yr was reported. There seems to exist an inverse relationship between size of basin and suspended sediment yield except for the smaller basins (Fig. 3-9).

McPherson (1975) studied 36 basins ranging in area from 78 to 1 427 km² and produced a very large scatter (Fig. 3-9). Possibly a large proportion of this variation can be explained by landuse differences. According to Chow (1964), landuse effects are only significant for 'small' basins less than 100 mi² (259 km²) but these data suggest that much larger basins are affected.

The basins were subdivided into three main elevation classes generally corresponding to the mountain, foothills and plains subdivisions (Fig. 3-10). There is a tendency for yield to increase with elevation but the mountain basins show very large variations.[19] This is possibly related to the varying proportions of unconsolidated Pleistocene and Recent deposits. Specific sediment yield data of the selected basins will be discussed in Chapter 8.

3.8 Units in the West Arrowwood Creek Basin

3.8.1 General Description

These units were first cultivated in the 1910's but the intensity of landuse varies considerably from one unit to another. Wheat, barley, oats, flax, rapeseed, and hay are the main crops and are cultivated with alternating fallow. Sizeable herds of cattle are usually kept to supplement the farmer's income and it appears that the number of cattle kept both past and present is related to general vegetation cover conditions in the coulees.

Much of the literature points to soil drifting in the prairies in the 1930's (Ellis 1954). A general wind erosion hazard was also emphasized. For the units studied it seems that only one small area in Merkel's section was affected. At this time, it should be stressed that other hazards need be given at least equal consideration.

Snow drifting alone, or accompanied by chinook winds, is not uncommon in winter. Farmers have reported that heavy drifting led to freeze-drying of the exposed soil which is then extremely susceptible to erosion during snow-melt period. Deep rills, developed under such conditions, have been reported. In mid summer, localized convectional storms of short duration but of relatively high intensity most frequently occur in July. Another erosion hazard is gullying, the initiation of which may be related to cattle trampling. Many examples can be cited in the study units.

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[19] Only data for prairie basins in the Cypress Hills area are available. They are probably not representative of cultivated watersheds in the prairies.

3.8.2 The Units

Andrews Section

This section is located in the southern part of the basin where topography is gentle. There is only one small coulee along the eastern fringe of the unit, the relief of which is only about 10 m. The regional slope is about 2 percent to the north. Parent material is re-sorted ground moraine in which calcareous sandstone of the Paskapoo Formation (Palaeocene Age) is incorporated. The unit was farmed since 1910 and in the past about 20 cattle were kept in the coulee though this practice was halted in 1969. At the time of survey, over 90 percent of the whole area was cultivated (Fig. 3-11).

Campbell Section

This section lies on the upper slope of the relatively steep northeast part of the basin. Two major coulees run south-north, one on each of the east and west half-sections. The maximum relief of these coulees can be up to 30 m. The regional slope is about 6 percent to the north. Parent material is mainly a thin layer of re-sorted glacial till. Bedrock is very close to the surface and outcrops of sandstone occur in the coulees. Past and present cattle activities have produced generally fair to poor coulee conditions. Slumping, gullying, and development of barren slopes almost to a badland type of condition was observed (Plate 3-3, Fig. 3-12), and incipient gullying is taking place (Plate 3-4). About 65 percent of the unit is ploughed and in 1973 some 75 cattle were grazed in the unit. In the coulees, slopes are generally steep to moderate.

Merkel Section

This unit is about 5 km southwest of the Campbell section and is at mid-section of the regional slope which runs roughly east-west at an angle of 4.5 percent. The heads of two coulees, one in the north and one in the southeast, are found. A third coulee runs westwards from the central part of the section. Although the regional slope is steeper, coulee entrenchment is less spectacular than in the Campbell section and therefore relief is lower, about 15 to 20 m at the most. Parent material is re-sorted ground moraine with a thickness of about 3 m. Sandstone outcrops only in the coulee bottom in the southeast. Soil drifting in the 1930's removed the top soil and deposited sand in the northeast part of the section (Fig. 3-13, Plate 3-5). Part of this deposit is still exposed. At site #3 [20] 12 cm of eolian deposit is found. A big gully head was observed at the head of the westward draining coulee where sample #6 is located. Down this coulee towards the western edge of the section is a small area of barren slopes. At the time of survey, the gully head is artificially protected. Other than this, the coulees are in generally fair condition.

Exposed cuttings close to a small dam along the northern edge of the section have been badly eroded by rilling and significant amounts of soil have been deposited in the ditches (Plate 3-6) whence they eventually find their way to the West Arrowwood Creek. Mr Norm Merkel, owner of the eastern half section, recalled that many such small earth dams had been built in the area but they were always rapidly eroded and became useless. A large amount of gravel had to be found to protect these slopes because colonization by vegetation is far too slow to arrest erosion.

In total, about 80 percent of the area is under cultivation and 80 to 110 head of cattle are grazed annually.

Steiner Section

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[20] These refer to sampling sites. Sampling procedure is described in Section 4.5.

This section is in the east-central part of the basin where slopes are gentle. However, entrenchment of a major northeast-southwest draining coulee is still rather pronounced giving a relief of about 20 m. Parent material again is re-sorted glacial till overlying grey sandstones of the Paskapoo Formation which outcrop at the bottom of the main coulee. Coulee condition is generally fair to poor with shallow slumps and receding cut banks evidenced. In at least one case slumping is related to a frequented cattle trail (Plate 3-7). Upstream development of cutbanks, according to recollections of Mr Steiner, takes place at the rate of at least 100 m in the upstream direction over the last 50 years. Comparison of the present position of the cutbank with its former position on the enlarged air-photo (Fig. 3-14), suggests the removal of an estimated 250 m³ in the last 11 years. There is no doubt that such a process is active at the present time (Plate 3-8). Other cutbanks are observed further down the coulee (e.g. at site #10, #11). Part of a slough is found in the northeast part of the unit.

About 75 percent of the area is presently under cultivation and about 35 head of cattle are grazed annually.

Weber Section

This is in the northwest part of the basin, about 3 km from the rather ill-defined water-divide. Regional slope is about 4 percent to the southeast and relief is about 20 m in the coulee located in the northeast part of the unit. A small dam has been constructed recently for water storage in the coulee. Parent material is a thin layer of re-sorted glacial till.

Probably as a result of local slope steepening, and the shape of slope plan, spring runoff tends to concentrate and produce a considerable amount of erosion at the northeast corner of the southeast quarter-section (Plate 3-9 , Fig. 3-15). This was observed for two consecutive years when the field was under fallow.[21] Otherwise the area is generally in fair condition. No cattle have grazed the unit since 1968. Except for the northeast corner, the whole unit is under cultivation at the time of survey. A small area of unconsolidated fill related to construction was mapped as a B3 unit[22] immediately east of the dam.

3.9 Units in the Pekisko and Stimson Creek Basin

3.9.1 General Description

The history of human occupation of the foothills areas is generally similar to that in the prairies, except that many forested areas were cleared. Because of the relatively short history of clearing, e.g. in the Spruce Ranching section, traces of a former Brown-Wooded profile, on which is superimposed a Chernozemic Ah under the present grassland vegetation, are evident. More recent clearings (in the last 5 to 10 years) left a former forested F-H layer still intact (e.g. in part of McMurtry section).

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[21] It is interesting to note that the farmers recognized only a very small erosion problem on their land when they were interviewed.

[22] The mapping procedures are described in Section 4.4

Also the generally thin soil horizons in part of this area probably reflects former periods of intensive grazing.[23] Today, grazing is still the dominant type of activity, but again there is marked variation in the intensity of use.

Visible erosion features in the area, however, are very limited in extent. Major slumping probably took place in historic times but minor slumps occur on river banks where downcutting produces steep barren slopes. Some minor gullying takes place where cattle concentrate.

3.9.2 The Units

Blades Section

This section is located at the eastern waterdivide of the Pekisko Creek Basin. The eastern part drains into the Upper Mosquito Creek Basin.

The main feature of this section is a north-south sandstone ridge that forms the eastern waterdivide of the Stimson Creek Basin. A moderately steep slope joins the narrow ridge top to a terrace level of the Stimson Creek in the west. To the east, the slope is relatively gentle and a uniform slope grades into a knob-and-kettle topography.

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[23] Peak periods dated back to the 1910's.

Parent material is mainly glacial till and outwash. But near the ridge top and on the steeper west facing slope, parent material is sandstone bedrock of the Paskapoo Formation (Palaeocene Age). Soils developed are mainly Chernozemic, ranging from Thin Black to Black. At a few sites (#3, #60, #63, Fig. 3-16), degraded profiles were observed. On the gentler east facing slope is found a prominent quartzose conglomeratic erratic (50 m south of site #69) and a linear feature that tapers from the south to the north resembling what Stalker (1973) described as a *Murdin*. The knob-and-kettle topography is characteristic of dead-ice moraine features usually found much further to the east.

The ranchland conditions are generally fair to good. Only one minor slumping scar is located in mid-section of the west-facing slope. Many north facing slopes are mantled by aspen (and some willow) and sparsely covered slopes are confined to the upper reaches of the westward flowing creek. The amount of sedimentation in the sloughs, however, is considerable. Ranchers report a great reduction in the depth of the largest slough in recent years.[24]

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[24] They said because of sedimentation, "formerly a horse can be sunk in the slough totally unnoticed but now even a calf can walk across."

Cartwright Section

This section is located in upper Stimson Creek basin, immediately outside the Forest Reserve. A small creek draining a lake-marsh area enters the section from the northwest and cuts the section diagonally in two. A second creek, Miller Creek, drains the southwest part of the unit. A prominent ridge runs along the east and northeast. The total relief of the area is about 170 m.

There is considerable diversity in the type of parent material and subsequently the degree of soil profile development. Residual soils developed from sandstone of the Belly River Formation and conglomerate of the Cardium formation (Cretaceous Age) are found in the east and northeast part of the section. Sandstone outcrops are located along the main ridge and along cutbanks of Miller Creek close to sample site #32. Glacial till of varying thickness, underlain by shale and silty shale of the Upper Albertan Formation, mantle the rest of the section. The linear structure southwest of the main creek may be related to a small dead ice block left behind after ice retreat. (Note its location in the valley). Soils range from Regosolic to Thin Black for steep to moderate and gentle slopes. Some Brown-Wooded soils are also present. 'A' horizons are usually very thin. In the northeast half of the section, shale bedrock is incorporated in the till deposits.

At least two terrace levels can be identified in the valley. Their elevations are below a prominent slough in the southeast at the lower slopes of the main sandstone ridge. It appears that these are developed on reworked till. Most of the terrace soils are Brown-Wooded except for sites #15 and #32 which seem to qualify as Black Chernozem. The present flood plain is very swampy and the creek flows as a meandering trickle.

The major erosional feature is a large slumping scar above the upper terrace level in the north-east (Fig. 3-17). Judging from the absence of deposits at the scar base, slumping must have taken place some time ago. This is mapped as an A3 unit. Another area of sparse cover is along the left bank of Miller Creek where the valley cut through thin till on bedrock.

Smith Section

This is at Upper Stimson Creek, about 10 km above the Chain Lakes. The major geomorphological feature is a broad north-south ridge capped by sandstone of the Belly River Formation. The ridge top is about 300 m above Stimson Creek which drains the southeast part of the unit. The ridge is flanked by a narrow valley in the west and broader till plains to the east. It is possible that the main ridge marks the western-most boundary of the Laurentide ice sheet. Also there is no good evidence of mountain glaciation. The valley west of the ridge has a sharp V-shaped form (Plate 3-10) and a large cutting on a terrace level east of site #5 (Fig. 3-18, Plate 3-11), shows a sand and gravel deposit probably of fluvial origin. Most of the soils in the western part of the area are residual soils developed from sandstone and some shale bedrock. They range from Regosolic to Brunisolic.

Fair to poorly covered areas are confined to terraces and steep slopes of the main Stimson valley.

Spruce Ranching Section

This lies in the central part of the Stimson Basin where Shepperd Creek, a major tributary of the Stimson Creek, flows west-east to join it about 5 km downstream of this section. The creek now has a very small meandering channel across a swampy floodplain. The major relief of the area is a narrow ridge in the west developed on Belly River Sandstone. Rock outcrops at the ridge tops. East of this ridge is found an extensive till-outwash-lacustrine plain.

3.10 Units in the Three Point Creek Basin

3.10.1 General Description

There is a sharp difference in landuse between the units outside and inside the Forest Reserve in the Three

Point Creek Basin. Grazing, raising of hay crops, and to some extent use to development of weekend villas[25] and oil/gas wells are commonplace outside the Reserve. Within the Reserve, use is confined to small scale grazing and various forms of recreational landuse like campgrounds.

There is a general absence of prominent erosional features except for steep barren cutbanks along the main Creek.

3.10.2 The Units

Charmes Section

This section is located in the lower basin, about 7 km west of Millarville. The main Creek drains the southeastern corner of the section and is flanked to the north by low sandstone ridges which descend into the Creek as a series of terraces. Tributary to the main Creek is a coulee from the northwest and two smaller ones to the east.

Parent material ranges from sandstone and shale bedrock to glacial till, outwash, and alluvial deposits. However the dominant soil type is Degraded Black Chernozem. Thin Black is developed on steeper slopes and Black Chernozem on terrace levels. At sites #21 and #27, gleyed 'B' horizons were observed. These poor drainage sites may be related to shale bedrock.

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[25] Some of these areas are only 30 minutes' driving distance from Calgary

The major erosion problem in the area is related to cattle trampling. In the northeast quarter-section, trampling on a moderate slope (9.5°) has produced a totally barren area of approximately 600 m^2. Fair cover conditions are found along the central ridge. This is mapped as an AB2 unit (Fig. 3-20). Similarly disturbed areas in the west along the main coulee is mapped as A2 areas. In the south two hay fields are mapped as B3 units.

McMurtry Section

This section is in the southeast corner of the Basin. The basin-divide runs along the ridge top in the northeast, and this ridge descends into a broad valley in the southwest. The total relief of the area is about 120 m.

Bedrock is mainly Upper Alberta Shale in the valley and Belly River sandstone on the ridge top. Lacustrine deposits cover the main valley bottom. The soils developed varies from a Black Chernozem (gleyed near valley bottom) to Brown Wooded in the north and northeast. Very typical Bm horizons were observed along the dead-end road in the north. Soils under a hay crop at Site #13 (Fig. 3-21) show gleyed 'A' horizons.

In recent years, the northern part of the area is being cleared for various purposes. Both sheep and cattle are reared.

Northfork East Section

This section, about one km east of the Reserve boundary, covers part of the upper Three Point Creek valley. Total relief of the area is about 150 m.

Except for the ridges to the north and south, most of the valley area is covered by outwash and alluvial deposits. A good exposure along the trail on the north bank close to site #8 (Fig. 3-22) shows outwash resting on Belly River sandstone and interbedded shale (Plate 3-12). Two major terrace levels are observed. Soils developed from the parent materials show a distinct north-south variation. South of the valley, all sample sites indicate good development of Brown Wooded soils and in the southwest leaching has proceeded far enough for some soils to be classified as Podzolic.[26] North of the valley, soils are Regosolic. On terraces, they are variable but mainly Brown-Wooded. Gleying is observed at site #8.

Northfork West Section

This section is at the headwaters of Ware Creek, a major tributary of Three Point Creek and immediately southwest of Missinglink Mountain underlain by Belly River

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[26] E.g. at sites #15, #16, & #17, the 'B' horizons are very brown and might qualify as Mini Humo-Ferric Podzol.

Sandstone. The topography at this elevation is almost 'mountainous'. Total relief is about 250 m.

Parent material varies from sandstone and shale bedrock of the Alberta Group to thin till in the southeast and alluvial deposits in the valley bottom. Soils are dominantly Brown Wooded. A few degraded profiles such as at site #6 (Fig. 3-23) was observed. Thin Black to Black Chernozem is found on grassed slopes.

Ware Southwest Section

This is located only about 2 km northeast of the previous section and is within the catchment of Link Creek, a right bank tributary of Ware Creek. Topography is more subdued for the most part and total relief is about 210 m.

The ridges to the south are underlain by Cardium sandstone whilst the one in the northeast is underlain by sandstone of the Blairmore Group. Between is a broad area of moderate to gentle slopes developed on Lower Alberta Shale. Residual soils, however, only constitute a small area. Till covers extensive areas and outwash and alluvial deposits are found along the three creeks from the west, the southwest, and the south.

The soils are dominantly Brunisolic. On north facing sites (such as #9 and #14, Fig. 3-24), very brown Bf horizons were developed. These soils may be Mini Humo-

Ferric Podzol. Along the bottom of the narrow valley of Link Creek, gleyed horizons occur. At a site 50 m south of #18, placic layers were observed below the Bg horizon.

This valley has been used for grazing purposes, and therefore, south facing slopes close to the valley and gentle slopes along the alluvial valley are not very well covered. In the northwest, about 20 m outside the section boundary on fine alluvial deposits is part of an abandoned trail now developed into a gully. Sample #11 was collected here.

3.11 Units in the Cataract Creek Basin

As in upper Three Point Creek area, access problems confine the study of Cataract Creek to three units in the east. However, a great variety of landscape is covered within the three units.

Cataract South Section

This area is located at the headwaters of Wilkinson Creek, about 2 km west of Plateau Mountain. Bedrock geology is considerably more complex than many foothills units. The eastern half is underlain by highly faulted Spray River and Rocky Mountain siltstone and sandstone. To the west are in decreasing amount of coverage : Fernie Shale, Kootenay Shale and Blairmore Sandstone. Outwash deposits in the south are cut into by a west flowing tributary of the Wilkinson Creek.

Shale bedrock is exposed in the central north-south valley where one of the plot sites is located.

Soils developed are Brown-Wooded on moderate to steep slopes and Humo-Ferric Podzol on gentle slopes. The horizons observed (such as at site #10 and #11, Fig. 3-25) are very similar to Crossley's (1951) description of Podzols in the Kananaskis valley. On gentle slopes close to the main creek were observed peaty sites which may be the equivalent of the 'Hangmoor Peat' of Crossley (1950). The thickness of peat varies from over 30 cm at site #3 to 10 cm at site #14. At site #9, peat occurs at 10 cm below the surface, underlying a thin Bm horizon. The peat formation is related to poor drainage, probably as a result of the relatively impervious nature of the underlying deposit and bedrock.

Areas of high erosion potential are confined to the cutbanks, especially those in the central valley where plot #C2 is located (Plate 3-13).

Cataract North Section

This section is located at the mouth of the basin in the north. Wilkinson Creek drains to the southeast and it joins Cataract Creek at a bridge crossing in the northeast. The gauging station of the basin is found at the edge of the map area about 600 m downstream from the bridge.

Bedrock is dominantly Blairmore and Kootenay Sandstone in the eastern two-thirds and upper Alberta Shale in the west. Deposition in the main valleys is extensive, including alluvial and outwash deposits. Soils developed are similar to those in Cataract South section.

Apparently the northern half of the section has suffered from a recent fire, probably not more than 20 years ago, judging from the height of the regenerated conifers. Thus many steep areas show removal of the L-H layer exposing the medium to highly erodible Bm horizons. These areas are mapped as A2 and A3 units (Fig. 3-26). Shallow slumping along cutbanks are also more common along these larger valleys. Plot #C4 is in fact located within a slumping scar.

Cataract Central Section

This is located on the forestry road east of Wilkinson Creek valley and is midway between the two other units. Bedrock and surficial deposit distributions are similar to Cataract North section. Probably as a result of a recent fire, much of the eastern slopes are exposed and eroded of its thin soil cover. Only large sandy fragments remain and it appears that they form an erosion pavement that tend to arrest further removal. These are mapped as A3 units. Poorly covered sites adjacent to the barren ones are mapped as A2 units (Fig. 3-27).

CHAPTER FOUR

FIELD & LABORATORY TECHNIQUES

4.1 Introduction

In order that data collected in the field and in the laboratory can be compared, the techniques adopted should ideally ensure that either they are applicable in both the field and the laboratory situation, or if different techniques were used the degree of deviations should be known and possibly some means of conversion available. However, this is not always possible. Sources of error are numerous and the degree of experimental control is relatively low in the field situation. Erosion plots can be disturbed without notice and there are variables which are known to be significant but difficult to quantify in the field.

Laboratory tests are generally much more controllable and in most cases are reproducible. Thus the sources of error are generally more defined and in many cases can either be corrected or accounted for in the statistical analysis.

The field and laboratory techniques used in this study are described in this chapter. The items of field work carried out include installation and servicing of erosion plots, field mapping of selected units, soil and surface material sampling, and measurement of soil moisture, cover density, and bulk density. The laboratory work carried out includes rainfall simulation and analysis of various soil properties.

The erosion plots were installed in the fall of 1972. Servicing and maintenance at varying intervals were carried out in the summers of 1973 and 1974. This was accompanied by soil moisture, bulk density, and cover density sampling. Field mapping and soil sampling were completed in the 1973 field season. Laboratory work was started in September 1973 and completed in November 1974.

4.2 Erosion Plots

4.2.1 Previous Work

Many methods have been developed to measure soil loss. These include stakes (Schumm 1956), erosion frame (Campbell 1974), Gerlach troughs (Leopold _et al_ 1964), and plots of various sizes (Hayward 1967). Stakes are only suitable where rapid rates of soil loss occur. Gerlach troughs require an accurate delimitation of the catchment area and definition of slope length and curvature. There are also problems associated with the use of erosion plots but the fact that they come closest to the laboratory test conditions[1] makes them the most desirable technique for the present study.

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[1] i.e. soil loss is evaluated at a per unit area basis within a well defined boundary

The use of 'plots' to study runoff and soil loss was pioneered by Wollny in Germany (Baver 1938). The first plots used in America dated back to the 1910's.[2] Since the 1930's this has become the standard technique to determine the effect of different treatments, particularly among the state agricultural experimental stations.

Hayward (1967), analysed 102 papers dealing with soil-loss plot studies and indicated there were "three quarters as many plot designs as there were plot studies." Plot sizes have a very large range but the common size was 80 to 100 m^2. Details of plot design and construction have been given by Mutchler (1963) and Garcia et al (1963).

Despite a number of limitations which will be discussed, this technique is still widely used today. Recent work in Alberta by Toogood and Newton (1950), Toogood (1963), Campbell (1970), Wyldman & Poliquin (1973) and in New Zealand by Soons (1970, 1971), and Soons & Rayner (1968), have all utilized this technique.

The basic idea for 'plot' studies is to reduce the area under study to a controllable size. However, there are a number of limitations as suggested in the literature. The mere presence of structures changed the fenced areas into 'closed systems' and edge effects have to be assumed negligible. In a recent study, Ketcheson et al (1973), indicated that extreme caution must be taken to interpret runoff and erosion data from plots of different sizes. The assumption that plot measurements are unbiased and are representative of the area under study were questioned (Boughton 1967, Hayward 1967).

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[2] See Sampson and Weyl (1918) and review by Mutchler (1963).

For the present study, the primary purpose of the use of plots is to test how far the laboratory data are realistic and therefore most of the limitations of the plot technique discussed above become acceptable. Extrapolation of data, however, would require additional information such as sediment yield as controls. Otherwise data collected by this technique is better treated as indications of the relative erosion potentials of the areas under study.

4.2.2 Design of Erosion Plots

Erosion plots were designed for the present study (Fig. 4-1, Plate 4-1). The plot is made up of three planks of 15 cm x 100 cm x 2 cm timber fixed into the ground by fencing the upper end and two sides of the plot by 50 cm stakes. A trough of 115 cm length is sunk in the ground at the lower end so that its upper lip just reaches the surface of the ground. The joints between the lip and the ground are sealed by a layer of plastic fibre gum. The trough leads to a spout by which runoff and sediment are collected in a polyethylene bag supported within a rigid 20-litre plastic container. A 'guard' made of aluminium plate is screwed on top of the trough to minimize splash from below the plot.

4.3 Soil Moisture, Bulk Density, & Cover Density Measurement

4.3.1 Soil Moisture

The basic problem with soil moisture sampling is not so much the precision of each measurement but the large variability of the statistical population. Hills & Reynolds (1969) have illustrated the relationship between the number of samples and limits of accuracy in soil moisture sampling. Pilot studies in this investigation indicate that for the estimated variance of the samples, a sample size of five gives an accuracy limit close to ± 5 percent. This sample size was therefore adopted.

Each time the plots were serviced, five soil samples of the upper 10 cm were collected. These were oven-dried at 105°C in the laboratory and the loss in weight expressed as a percentage of the wet soil. This is preferable to the dry base method as explained by Robinson (1974).

4.3.2 Bulk Density

Various methods for determining soil bulk density are available (Blake 1965). An early attempt using a surface density probe (Rix 1965) caused a number of mechanical problems in this study. The use of the moisture probe alone to determine bulk density requires an accurate measurement of soil moisture content, and the method described above is just not accurate enough for the purpose.

A later attempt used a core sampler made available by the Department of Soil Science, University of Alberta. The sampler, fitted with copper rings of internal diameter of 5 cm, is gently hammered into the ground. Care is taken to stop hammering as soon as the top of the ring is flush with the ground surface. The entire sampler and sample (to depth of 10 cm) are then dug out. The cores are removed from the sampler and a sharp knife is used to trim the lower end of the core flush with the ring. Two to three cores of 100 cm^3 were taken from each site. The cores were oven-dried at 105°C in the laboratory. The weight of the core divided by its volume equals its bulk density.

However, the core-sampler method cannot be used in areas where the soils are extremely stony, or where bedrock is very close to the surface. In these cases, a simple excavation method was employed. In the field, a relatively large area of uniform slope is excavated. Free-flowing sand was then used to fill the excavation until the original slope is restored. The amount of sand used was weighed by a spring balance, accurate to ±0.05 kg. In view of the relatively large volume of soil excavated (>1 kg) the degree to which the original slope was restored was only estimated by gently sliding a flat-edge board along the excavation.

The excavated soil was collected, oven-dried in the laboratory, and weighed. The density of sand used was determined in the laboratory so that volumes used in the field could be calculated. The weight of oven-dried soil divided by the volume of sand used equals bulk density.

4.3.3 Cover Density

A 50 x 50 cm quadrat was used for the measurement of cover density. In this study, cover density refers to the cover at the soil surface level and is expressed in percent of bare ground. Both the point and area method were attempted. In view of the generally small percentage of bare ground measured, the area method is more accurate.

Cover density in a wooded area is effectively different from an unwooded area. Estimation of crown cover is inappropriate because rainfall impact is complicated by throughfall and wind direction. Thus, in the overall statistical analysis, cover density effect of wooded sites cannot be directly compared with non-wooded sites.

4.3.4 Infiltration

Some early attempts were made to measure infiltration in the field by a double ring infiltrometer (Hills 1970). These attempts indicate that this field technique is not suited to the purpose of the present study. Maintenance of a constant head is difficult on sloping ground. The manner and depth of insertion of the rings greatly affects measurement results. The most serious problem with this technique is that there is very significant difference between the infiltration of ponded water and natural rainfall (Branson, Gifford & Owen 1972). Comparison of infiltration rate by this method with natural rainfall intensity is unrealistic. Unless some means of rainfall simulation is possible in the field, infiltration is better measured in the laboratory.

4.4 Field Mapping

The primary objective of this phase of study is to develop a relatively simple classification scheme which has relevance to the study of soil erosion potential and which can be completed within a relatively short period of time so that soil sampling that follows can be carried out within the same field season. Given this basic objective, a simple 'parametric' system (Mitchell 1973) was adopted.

Of the four basic factors affecting water erosion potential, rainfall is external to the land system. Soil erodibility is measured in the laboratory and therefore variations in parent material and field soil properties were noted only in the field. Slope and cover are therefore the two remaining factors to be considered in the classification system.

To simplify the mapping procedure, only slope angle and ground cover density were considered. It was felt that for an exploratory type of study that transects the whole spectrum of landscapes from the plains to the mountains, consideration of such factors as slope length, slope curvature, cover type, species etc were beyond the scope of the investigation and added complications that could not be handled by the experimental design though some of these factors are important variables. Enlarged air-photos[3] formed the basis of the mapping process.

Field and topographic map analysis indicated that land slopes could be conveniently classified as : 'A' steep, 15° or greater; 'AB' intermediate, 6° to 15°; and 'B' gentle, 0° to 6°. In most instances the last category coincided with river flood plains, terraces, and hilltop sites.

Ground cover density was similarly classified into four groups : '1' totally undisturbed, 0 to 6 percent bare; '2' partially disturbed, 6 to 20 percent bare; and '3' poor cover, 20 percent or more bare ground. This latter category includes areas recently burnt-over, or places where severe cattle trampling or other intense disturbance has occurred. Completely barren sites were given a special category ('4'), and included scree slopes, bedrock surfaces, and many river banks.

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[3] Enlargement of air photos with scales at 1 : 15 840 & 1 : 31 680 to 6.5 times so that mapping was carried out at scales of approximately 1 : 2 400 & 1 : 4 800

Using these two basic criteria, slope and cover, each unit was traversed and sites of uniform slope and cover were identified; each site being a combination of slope classes : 'A', 'AB', or 'B', and cover classes : '1', '2', '3', or '4'. Thus sites such as AB4, A1, B2 etc. appear as fundamental map units. Any variations in parent material, soil etc. within each site were also noted in the base map. The final field maps are presented as overlays on top of reproduced air-photos (Fig. 3-11 to 3-27).

4.5 Soil & Surface Material Sampling

Based on results of field mapping, a sampling plan for each unit was devised. The main objective was to ensure that each site category was represented making it possible to assess the overall erosion potential of each unit. To sample every mapped 'site' would have required an unmanageable number of samples. Thus sampling intensity was lowered for sites which are well covered and therefore have relatively lower erosion potential. The total number of samples collected amounted to 233, varying from 5 to 30 for each unit (Table 4-1).

Within each site, a representative location was selected. These locations were selected away from the site boundaries if edge effects were thought to be important. A 50-cm square pit was dug to a depth where the 'B' horizon could be identified, and a sample of approximately 10 kg of material was collected from the exposed surfaces of the 'A' horizon. Where the 'A' horizon was thin, less than 5 cm, an additional sample of subsoil was taken. Additional samples of 'A' and 'B' horizons were taken for study of aggregation size, organic content and texture.

Using a hand level and a ranging rod two slope readings were taken along the maximum gradient 2.5 m from each side of the sample location. Then, using a 50 x 50 cm grid quadrat, four cover density readings, one upslope, one downslope, and two at either side of the sample location were taken. These readings, when averaged, gave representative slope angle and cover density at each site.

4.6 Laboratory Simulation Technique

4.6.1 Previous Work

Experience with field measurement of soil loss since the 1930's shows that because it is so dependable on natural rainfall, usually a long period of time is required to obtain the desired data. Also data is not reproducible for any one particular site except by duplicating plots. For these reasons and the costs of installation and maintenance involved, rainfall simulators were developed. In 50 years of development, the technique evolved from use of water cans (Duley & Hays 1932) to highly efficient units like the 'rainulator' (Meyer & McCune 1958) and the Edmonton-pattern simulator (Bryan 1970).

With the gaining of new knowledge in the interrelationships among raindrop size distribution, raindrop velocity, distance of fall, rainfall intensity and kinetic energy (Laws 1940, 1941; Laws & Parsons 1943; Wischmeier & Smith 1958), it became possible to consider these factors and their replicability in designing rainfall simulators.

Ellison & Pomerene (1944) developed a simulator made up of chicken wire sheet mounted below a watertank perforated with 6.4 mm holes. The wire sheet was covered by cheese cloth on which were threaded short pieces of wool yarn through the openings of the wire. A motor kept the mounted wire in motion so that drops from the wool yarn were scattered. Intensity varied from 12.2 to 37.6 cm/hr and two drop sizes of 3.5 mm and 5.1 mm were used.

The unit used by Ekern & Muchenhirn (1947) had hypodermic needles mounted to the bottom of a drop tower. Fall height was 10.5 m and 5 drop sizes from 2.75 to 5.8 mm were used. Intensity varied from 5.1 to 12.7 cm/hr.

Adams et al (1957) developed a portable rainfall-simulator infiltrometer which used 6.3 mm diameter glass capillary tubing as drop formers. The 5.6 mm drops fall 1 m to the soil surface and have the same kinetic energy as natural rainfall, average drop size 3.44 mm, falling at terminal velocity. Intensity used was 10.2 cm/hr.

The main criticisms of some of these units are : (a) that only high intensities (12.2 to 37.6 cm/hr) were used; and (b) that fall heights were too low so that the terminal velocity of natural rainfall was not attained (Epstein & Grant 1966).

With improvement in design techniques, Meyer & McCune (1958), developed a 'rainulator' which produced drop sizes of 0.5 to 4 mm, reproduced 70 to 84 percent of drop terminal velocities, and 80 percent of the equivalent kinetic energy at an intensity of 6.35 cm/hr. However, the flow rates of the jets used were too high and intermittent operation was therefore required. This meant short term variations in intensity at any one spot. A comparable unit for laboratory use was also developed (Bubenzer & Meyer 1965).

Epstein & Grant (1966), developed a laboratory rainfall simulator which had a fall height of 7.62 m and was capable of reproducing very closely the erosion index (EI) values of natural rainfall. Stainless steel tubing mounted under an applicator was used as drop formers. A similar simulator was constructed by Mutchler & Moldenhauer (1963). Bryan (1968a) developed the Sheffield pattern simulator and later (Bryan 1970), modified it to the more efficient Edmonton-pattern.* Farmer & Van Haveren (1971), used a laboratory simulator which produced drops from 0.5 to 5 mm.

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* Details of this simulator will be described in Section 4.6.2.

Fall height was 3.66 m and intensity varied from 7.6 to 16.8 cm/hr.

As a result of the growing popularity of rainfall simulators, their use has been extended to study of potential erosion rate by considering other variables affecting erosion. So far, variations in slope steepness, soil moisture content, and bulk density have been considered (Epstein & Grant 1966; Bryan 1968, 1970; Meeuwig 1970; Farmer & Van Haveren 1971). Effect of cover has also been simulated (Shvebs 1968, Kramer & Meyer 1969, Lattanzi et al 1974).

Young & Burwell (1972), attempted to compare soil and water losses from natural and simulated rainfall. The 'rainulator' was used in this study and the results indicated a very close correspondence. Adams et al (1959), also observed a general agreement between rainfall simulation results and field plot data in a study of Blackland Prairie soils of Texas. Apart from this, very little has been done so far to relate laboratory simulation and field runoff plot results.

As with runoff plots, rainfall simulation has limitations. The effect of slope length is often neglected (Moldenhauer & Koswara 1968). For disturbed samples, splash erosion tends to be over-estimated and wash erosion under-estimated (Bryan 1968a). The translation of soil loss figures during the test into annual soil loss figures is practically impossible (Bryan 1969).

However, the present study is concerned with relative soil loss per unit area and is not an attempt to estimate annual soil loss. Whilst errors in wash and splash estimates tend to cancel out when the total amount of loss is considered (Bryan 1968), the *relative* rates of loss established by laboratory simulation have to be tested against field data before being applied to estimate relative erosion potential in the field.

4.6.2 The Edmonton-Pattern Rainfall Simulator

Since this unit has been described in detail elsewhere (Bryan 1970; Appendix 4-1), only the salient features are presented in this section. To suit the purpose of this study, attempts were made to develop a suitable technique for the simulation of cover density (Section 4.6.4). The runoff collection system was modified to allow measurement of runoff rates. Variability in rainfall output and soil erodibility in relation to surface particle size distribution, bulk density, and moisture content were also studied.

The Edmonton-pattern rainfall simulator (Fig. 4-2) has a fall height of 2.59 m. The range of drop sizes is from 0.5 to 5.3 mm. For a 102 mm/hr intensity storm, the drop sizes produced are found to show too high a frequency for the smaller sizes when compared to drop sizes of natural rainfall at the same intensity published by Laws & Parsons (1943). Kinetic energy calculated on the basis of the drop size distribution observed, is 65 percent of the kinetic energy of natural rainfall of the same intensity (0.93 Watt/m^2).[5]

However, it must be noted that only approximate intensity-frequency relationships are known in Alberta. No measurement of drop size distributions of natural rainfall are reported and there is no reason to assume that the drop size information published by Wischmeier & Smith (1958) is applicable to the area under study. This fact necessarily poses a limitation of considerable significance when attempting to compare laboratory results with field conditions.

Another feature of the unit is the separation of splash loss from wash loss (Fig. 4-3). For time-rating of runoff, a 0.80 m trough sloping at a small angle was mounted in place of the wash collector at the base of the unit. The trough leads to the front of the unit where runoff is collected by a polyethylene funnel draining into 1 000-ml beakers.

One problem associated with the separation device is that the aluminium shield does not provide a complete protection of the slot outlet from direct rainfall. This is especially the case when testing is carried out at high slope angles. Another source of error in the separation occurs where splashed particles are collected on the inner side of the projected shield. Care was taken in the tests to remove this fraction separately and add to the splash loss collected in the splash can. Possibly a very small portion may be lost to the wash slot during the runs.[6]

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[5] According to the intensity-kinetic energy table published by Wischmeier & Smith (1958).

4.6.3 Calibration of the Rainfall Simulator

For the range of natural rainfall intensities observed (Section 3.6.3), the 102 mm/hr rate, was selected. This intensity for a 15 min period has a return period of about 25 years in the study area (Bruce & Storr 1968) and was used in a similar study of Alberta soils (Bryan 1974).

The 102 mm/hr intensity is produced using one pipe in each bank of the spray unit, with six nozzles of 0.79 mm diameter, and two of 0.39 mm diameter. For calibration, four standard 5-inch (12.7 cm) Casella rain gauges were placed in the sample pan with the slope set at 0°. The angles of the spray nozzles and the pressure regulators were then adjusted until each rain gauge records 51 ± 3 mm over a half-hour period. The intensity is checked every 30 to 50 runs to ensure consistency in the experiments. The nozzles are also frequently examined to eliminate carbonate deposits carried by tap water.

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[6] This may be significant in the cases with a relatively small amount of wash loss.

Because frequent calibration of the simulator revealed variations in rainfall output, an attempt was made to examine this variation by making 10-min runs for 10 successive times. The results of this test are shown in Table 4-2. The mean and standard deviation of this sample are 101.5 mm and 2.9 mm/hr respectively. As an approximation the ±3 standard deviation range is used to represent 99 percent of the sampled population. For this test, 99 percent of the output sample will fall within the range 92.8 and 110.2 mm/hr, or about ±8.5 percent of the mean.

Wischmeier & Smith (1958) found that soil loss is best correlated with the product term total kinetic energy x maximum 30-min intensity (EI_{30}). Thus it appears reasonable to interpret rainfall intensity in terms of this product term. For the values observed in the sample, EI_{30} value is 140.2 J-m/hr to 202.1 J-M/hr. For 30-min rainfall at 101.6 mm/hr, the EI_{30} value is 170.0 J-m/hr. Therefore the present sample suggests a maximum deviation of ±17.5 percent from the target rainfall intensity interpreted in terms of its 'erosivity'.[7] However, this is the maximum possible and is certainly excessive for 30-min runs because for the runs with a longer period, short term variations are dampened and therefore between-run variations should be much smaller.

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[7] The target rainfall erosivity assumes an average drop size distribution published by Laws & Parsons (1943). It is not known how well the simulated drop size distribution corresponds to observed distributions in Alberta.

4.6.4 Simulation of Rainfall Erosion

Apart from rainfall characteristics, other variables affecting soil loss were also studied. These include slope angle, cover density, and soil moisture.

Slope angles measured at each site in the field were plotted on a frequency diagram (Fig. 4-4). The data were divided into three groups relating to the three slope classes used in field mapping. In order to standardize laboratory studies, the range of total slope angles encountered in the field were reduced to three categories. Field slopes from 0° to 6° are represented by a 3° slope in the simulator; 6° to 15° by a 10° slope; and field slopes of 15° or greater by a 30° slope in the simulator.

Previous studies attempted to duplicate varying cover densities by using either dry straw (Shyebs 1968, Lattanzi 1974) or fiberglas electrical sleeving (Kramer & Meyer 1969). For the present study, 10 mm thick porous foam plastic sheets were used. Random patterns cut from each sheet gave the required percentages of bare ground. The sheet was indented by random stapling to simulate variations in cover surfaces and to allow movement of intercepted water as down stems and leaves. To standardize simulation procedures, all average readings of percentage bare ground in the field were plotted on a frequency diagram (Fig. 4-5), and grouped in such a way to approximate the classes used in field mapping : class '0' 0 to 1.9 percent bare; class '1' 2 to 7.9 percent bare; class '2' 8 to 19.9 percent bare; class '3' 20 to 99.9 percent bare; and class '4' 100 percent bare. Classes '1' to '3' are each represented by one single percentage in the simulator, *viz.* class '1' by 5 percent bare, class '2' by 15 percent bare, and class '3' by 45 percent bare.

Because runoff and erosion are greatly influenced by antecedent soil moisture conditions, these factors must also be considered in simulated erosion studies. Hence, in the laboratory, allowances are made for variations in soil moisture content. Two antecedent moisture conditions have been selected to represent these variations : an air-dried condition simulating erosion after a long drought and a field-capacity state simulating erosion when soil is moist.

4.6.5 Laboratory Routine

The laboratory routine established was that each sample would have three runs of one-half hour rainfall at an intensity of 102 mm per hour. All soil samples were air-dried before use. In order to ensure comparability of data obtained, each sample was passed through a 4 mm aperture square-hole sieve. The sieved samples were then packed into a sample pan above three layers of 10 mm glass beads which were covered with a layer of tissue prior to having the soil added.[8] The tissue and the beads provided drainage for the sample and ensured that downward wash of particles did not take place since only splash and runoff erosion data were required. The soil was levelled to the top of the pan which was then adjusted to the required slope angle. Bulk density of the same sample was measured by packing soil in an aluminium container and weighing.

The first period of rainfall, 30 minutes on air-dried soil, was followed by a drainage period of a further 30 minutes. Then an additional 30 minutes of rain took place. Whenever the cover density fell into class '1', '2', or '3', a third period of rainfall after another 30 minutes of drainage was produced with the appropriate cover density sheet placed over the sample.

During the first two runs, the amount of runoff for selected samples was recorded at 5-min intervals. This gave a time rating of the production of runoff under steady rainfall. Total runoff was recorded for all samples. During each rainfall period the eroded materials (splash and wash) were collected separately. The splashed portion was passed through a 63-micron sieve, and the coarse sediments washed into a dish to be oven-dried; the sediments passing the sieve were collected in a settling container, then removed by decantation and oven-drying. Runoff sediments were deposited in a container and trough below the sample pan, then separated by oven drying and weighing.

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[8] A standard procedure for packing was followed. Sieved soil was transferred to the pan without compaction. Excess soil was removed by rolling a 20 mm diameter wooden rod on the edges of the pan. The procedure was followed for testing bulk density in the laboratory.

4.7 Analysis of Soil Properties

Aggregation size, soil texture, organic carbon content, and bulk density were analysed in the laboratory. The bulk of this part of the work was done in the fall and winter of 1974.

4.7.1 Aggregation

The Yoder (1936) wet sieving technique or variants of it, has become the standard technique for testing soil aggregation size (Kemper & Koch 1965). Although in a sense this technique also measures aggregate stability, it should be remembered that the forces involved are mainly water slaking and to a minor degree abrasive and impact forces during sieving. Aggregates remaining undispersed during wet sieving may or may not become dispersed under raindrop impact. This latter force is not considered in the established technique.

Four sieves : 2.83 mm, 2 mm, 1 mm, and 0.5 mm were used in the analysis. A Yoder (1936) type sieving machine raises and lowers the nest of sieves 4 cm through water approximately 30 times per minute. Air-dried soil was first passed through a 4 mm square hole sieve to ensure that the sample used is comparable to the one tested under simulated rainfall. Two 50-g subsamples were taken. One was oven-dried to give the basic weight and the other transferred to the top sieve. The sample was wetted for one to two minutes before sieving began. Each sample was sieved for 20 minutes and the contents of each sieve oven-dried and weighed. The four fractions were then emptied into a 600-ml beaker and soaked with calgon overnight. The sample was agitated with a shaking machine for 1 minute, wet sieved the next day through the same nest, and sand fractions collected, oven-dried and weighed. The weight of water stable aggregates (WSA) of a given size is given by :

$$W(a) - W(s)$$

where W(a) is weight of aggregates and W(s) is weight of sand fraction. The basic weight is also corrected :

$$W(cs) = 50 \text{ g} - W(ts)$$

where W(cs) is corrected basic weight and W(ts) is total weight of sand fraction. Percentage weight of WSA of a given size is then computed by dividing weight of WSA by the corrected basic weight.

Aggregation size is reported in six aggregation indices : WSA > 0.5, WSA > 1.0, WSA > 2.0, WSA > 2.83 mm, Geometric Mean Diameter (Mazurak 1950), and Mean Weight Diameter (Van Bavel 1950). All indices are reported with reference to the basic weight.

One problem with the sand correction technique is that when a considerable amount of coarse sand is present, the corrected basic weight becomes much smaller than 50 g, sometimes less than 25 g. This induces a relatively higher margin of error in these more sandy samples. Also sand correction requires the complete dispersion of the sample. Any mechanical means used to help achieve dispersion will break down highly weathered sand particles. For this reason sand-corrected data may become very unrealistic, and a number of samples from badly eroded sites were discarded (Section 6.3) from the final statistical analysis.

4.7.2 Soil Texture

For this study, a modified hydrometer technique (Bouyoucos 1961) is preferable to the pipette (Kilmer & Alexander 1949) because it is faster.

Some preliminary studies also indicated very significantly different results with and without using hydrogen peroxide (H_2O_2) to destroy the organic matter present (Appendix 3-2). This use for Alberta soils is also recommended by Toogood & Peters (1953).

Two 20-g sub-samples were weighed to the nearest 0.05 g from a sample that passed through a 2 mm sieve. The samples were transferred to 600-ml beakers. Then, a few drops at a time, 30 percent hydrogen peroxide was added, and the digestion completed by warming the sample for at least 2 hours at 90°C on a hot plate. The procedure was repeated if visual inspection indicated incomplete destruction of organic matter. Water was added and the samples left undisturbed for 24 hours before the supernatant water was siphoned off. One sub-sample was then oven-dried to give the basic weight and 50 ml of 5 percent sodium metaphosphate added to the other. This latter sample was soaked overnight. The next day, the sample was agitated in a standard shaking machine for 5 minutes and then transferred into a 1 000-ml cylinder. Tap water was added to make up the suspension to 1 000 ml. When the temperature of the suspension became stabizied, usually after two to three hours, the suspension is thoroughly mixed for 1 minute, using a brass plunger, and the hydrometer inserted to take readings at 30 sec, 1 min, 3 min, 30 min, 4 hrs and 8 hrs. Each time, a temperature reading to the nearest 0.1°C was taken.

Data computation follows the standard procedure documented by Day (1965). A table relating observed hydrometer readings to 'θ_L' values (ASTM 1954) was prepared (Appendix 3-3).

4.7.3 Organic Matter

Available techniques for analysis of organic matter content are usually rather involved (Broadbent 1965). That is perhaps the reason why the Walkley-Black or the Schollenberger method has become so widely accepted (Allison 1965). A modified Walkley-Black method described in Allison (1965) was followed in the present study.

A small sample was ground to pass through 0.5 mm sieve and two sub-samples were weighed out (normally 0.5 g but larger ones up to 5 g have to be used for soils of low organic carbon content). One was oven-dried to give the basic weight, the other was transferred to a 600-ml conical flask and 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added. Then 20 ml of concentrated sulphuric acid (H_2SO_4, 98 percent) was rapidly added and the flask swirled for not less than 30 sec. When cooled, 10 mg of silver sulphate powder (Ag_2SO_4) was added as a catalyst and about 250 ml of distilled water was added. The excess dichromate was then titrated with 0.1 N Mohr's solution,[9] using 5 drops of phenylanthranilic acid as an indicator.[10] At the end point of the titration, the colour changes rapidly from dull blue to emerald green. A blank determination made without soil served to standardize the solution for each set of 10 to 20 samples.

Percent organic carbon (uncorrected) was then calculated as :

$$[T(b) - T(a)] \times 0.3 \times M/W(s)$$

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[9] Mohr solution was prepared as described in Kononova (1961)

[10] The indicator was prepared according to the method described by Kononova 1961, p.345.

where T(b) is blank titre, T(a) is actual titre, M is the normality of the Mohr solution, and W(s) is weight of oven-dry soil in grams.

The total percent organic carbon is obtained by multiplying the uncorrected value by 1.33 (Hesse 1971). This is a correction for incomplete digestion of the reaction.

4.7.4 Bulk Density

Laboratory bulk density was simply determined by packing (as in preparation of sample for rainfall simulation study) a subsample that passes through a 4 mm square hole sieve into an aluminium container that has a volume of 134 cm^3 and weighs 24.2 g. Laboratory bulk density is equal to

$$[W(t) - W(c)]/V(c)$$

where W(t) is total weight, W(c) is weight of container, and V(c) is volume of container.

CHAPTER FIVE

LABORATORY SIMULATION DATA & SOIL PROPERTIES

5.1 Introduction

All samples were collected from the 17 selected units during the summer of 1973. Table 4-1 shows a distribution of these samples with respect to unit. The location of the sample sites are shown in Figs. 3-11 to 3-27.

One-hundred-and-fifty-three samples were analysed in the laboratory during 1973-74. The samples were tested for erodibility, infiltration, aggregate size, organic carbon content, texture, and bulk density.

During the rainfall simulation studies, soil samples were tested at three slope angles 3°, 10°, and 30°, and at three cover densities : 5, 15, and 45 percent bare ground. Table 5-1 shows the classification of tested samples with respect to slope and cover classes.

This chapter endeavours to present all laborataory testing results. Soil loss and runoff data are treated in Sections 5.2 to 5.4. Emphasis is placed on the examination of within and between run variations. Soil properties data are considered in Sections 5.5 to 5.10. It is deemed most important to attain a thorough understanding of the interrelationships among the soil variables at this stage. Thus

Section 5.8 examines the reciprocal effects of clay and organic content on aggregation. Also, to gain some insight into the operating erosion processes during rainfall simulation, the relations between soil loss variables and soil properties are investigated and presented in Section 5.9.

It must be emphasized at this juncture that the test results must be weighed judiciously before they should be generalized because the samples collected are by no means random. Also, it is recognized that generalizations over broadly identifiable zones, but which have very considerable amount of within-zone variations, may have limited applications. In this chapter, constant reference to sample group names such as prairie soils or forested soils is only a convenience and does not imply any conclusive remarks on their respective populations.

5.1.1 Test of Data Variability

Rainfall variability has been discussed in Chapter 4. Two other tests, using one control sample (#CC11), were conducted to evaluate actual variability in soil loss and variability due to surface particle size distribution. This sample, #CC11, has 63 percent sand and 15 percent clay. Other pertinent data are available in Appendix 5-1. Both tests were conducted at a slope of 30°. Table 5-2 shows the results of the two tests.

For the first test, the data suggest that the simulated rainfall variability is smaller than the ± 17.5 percent obtained in Chapter 4. Despite the small number of samples used, the standard deviation is 46.2 g/m². Three times the standard deviation is 138.5 g/m² and this is about ± 12.4 percent of the mean.

The second test is concerned with the surface particle size distribution. Five samples were prepared of which two had more coarse fragments on the surface, one had more fine particles and two others were prepared in the same way as the set in the first test. The result indicates that with more coarse particles on the surface initially, less erosion will occur. The sample with more fines at the surface shows much higher soil loss.

The standard deviation of this sample is 259.8 g/m² which is about 23.5 percent of the mean (Table 5-2). This test therefore demonstrates the possibly much larger source of error due to variations in distribution of surface particle size relative to rainfall output. This is particularly significant for sandy soils. Because of this result, special attention was paid to ensure that the surface half of each rainfall simulation sample was thoroughly mixed and visible departures from the average particle size distribution at the sample surface were avoided.

5.2 Data Manipulation

5.2.1 Soil Loss Data

The size of sample pan used in the simulator was 30.5 x 30.5 cm. The amount of soil loss was measured in grams. The final unit adopted for measurement of soil loss was g/m². This applied to splash and wash loss of all three runs. The data had also to be corrected for slope because as rain falls vertically, an increase in slope reduces the total rainfall catch. This amount is proportional to the secant of the slope used. This also applied to splash and wash loss of all three sample runs. For easy reference, abbreviations of the soil loss variables were preferred and they are shown in Table 5-3. Other variables are also included in this Table.

5.2.2 Runoff Data

Under naturally occurring conditions, precipitation (P) is lost through interception, evaporation (V), infiltration (F), and runoff (U). Where vegetation is absent,

$$P = V + F + U.$$

In the laboratory situation and for a small unit area, evaporation is assumed to be minimal during a 'short' rainfall period so that

$$P = F + U.$$

For the simulator used in this study there are two additional variables to be considered. One is loss of water through splash (Sh) and the other is direct rainfall into the collection trough (Rd) so that

$$P = F + U + Sh + Rd.$$

For a given slope, 'P' is a constant. Comparison among different slopes requires a correction for difference in area due to change in slope. Amount of water loss through splash (Sh) was not measured but laboratory observations indicate that the maximum value of 'Sh' is small relative to the sum 'F + U'. 'Rd' theoretically is another constant factor for fixed 'P' and slope.

If the value of 'Rd' is known, then

$$P - Rd = F + U \text{ or } F + U = k'$$

and thus for a given slope

$$U = k' - F.$$ [1]

'U' may therefore serve as a readily available index of infiltration.

Using an empty soil pan, attempts were made to measure directly the value of 'Rd' for different slopes in the simulator. These attempts were unsuccessful mainly because they exposed a large surface area inside the sample pan for splash to take place. Thus measured values tend to be too high, far higher than some of the actual recorded 'U' values. This was true despite attempts to reduce splash by placing foam sheets in the pan.

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[1] The reason why 'F', a direct index of infiltration, is not used in this study, is that the final distribution of 'F' is very strongly left-skewed. Transformation into a normal distribution would require the reverse process of finding an empirical constant k'' where k'' is greater than the maximum value of 'F' and then choose a suitable transformation to produce a normal distribution. In this case it is preferable to use 'U' as the infiltration index.

The only other way to overcome this problem is to examine the runoff data. Plotting of some runoff rating curves indicates that because there is a small time lag between runoff leaving the sample pan and arriving at the runoff collector, data for the first 5-min has a high variability depending on how wet the runoff trough system is and this in turn depends on time elapsed since the previous run. Therefore, before any analysis was made, only the 5-min to 30-min runoff is considered. All future reference to 'U' pertains to this variable.

Histograms for runoff were plotted for three different slopes (Fig. 5-1). They show distinct peaks that are roughly similar to the estimated amount according to the calibration results. Runoff and wash erosion were then examined in bivariate plots (Fig. 5-2). In practically all cases, it is possible to hand-fit a curve to the data with a shape that indicates wash loss generally increases without a corresponding increase in runoff when wash loss is small.

Based on these curves, correlation profiles were then devised using wash erosion and 'U - Rd' as variables, the

'Rd' values being so selected that they cover the regions suggested by the hand-fitted curves (Fig. 5-3). The final 'Rd' values selected were the ones that give the best correlation between wash and runoff minus direct rainfall.

Admittedly this method is not very accurate, the final 'Rd' values selected have a probable error of up to ± 0.01 mm, but, as can be seen in Fig. 5-2, variations in rainfall input plus random error tend to produce a small range rather than a specific value for 'Rd'. Therefore, it is in fact impractical to select any one particular value. Also within each region tested, the difference in 'r' for different Rd's are relatively small and should not significantly affect the results.

All runoff data were expressed in mm. Slope corrections were made for these data as described for soil loss data in Section 5.2.1. The final 'Rd' values selected are : 2.42, 2.48, and 3.54 mm for 3°, 10°, and 30° slopes respectively.

5.3 Soil Loss Variations

5.3.1 Within Run Variations

Since every sample was tested under a 'dry' and a 'wet' condition, two complete sets of data are available. For each set splash loss is separated from wash loss. A third set of soil loss data using cover simulation are available for most of the samples tested. This is also discussed in this chapter.

Descriptive statistics for untransformed soil loss variables are presented in Table 5-4. Generally most of the distributions are right-skewed. Out of all trials for transformation, the log (to base 10) transformation is found to be the most suitable.[2] This agrees well with the expectation that the processes responsible for soil loss operate on an exponential scale.

Transformed soil loss data are presented as histograms in Fig. 5-4a, subdivided according to slope. This is because only when slopes are identical can variations in soil erodibility be directly assessed. Generally the transformed data are normally distributed. But a number of distributions are either bimodal or skewed. In fact most of the histograms in the 3° slope class are bimodal. Examination of Table 5-1 indicates that bimodality of this sample is due to the presence of some highly erodible prairie soils which are or had been under cultivation. These are differentiated from the relatively non-erodible soils mainly from the rough pastures of the foothills.

After transformation, splash loss in the 30° slope class becomes left-skewed. This tendency is in large part due to the high erodibility of a number of prairie samples which appear to attain a fairly constant rate of splash loss in the wet run and that is why a stronger skewness is developed for SPASHW.[3]

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[2] These transformations are required to satisfy one of the basic assumptions for multiple regression analysis to be presented in Chapter 6.

The third set of data is associated with cover density simulation. Because the number of samples in each cover category varies from one slope class to another (Table 5-1), the distributions tend to be more irregular.

However, when these distributions are considered without subdivision (Fig. 5-4b), many of these departures from normality disappear. Statistical tests of 'goodness of fit' of these distributions to normal curves of identical mean and standard deviation are available in Appendix 5-2.

5.3.2 Between Run Variations

Classical studies (Horton 1933, Neal 1937) found that under identical conditions, erosion associated with a 'moist' soil is much greater than with a 'dry' soil. This was later termed the factor of 'antecedent moisture content' (Tisdall 1951). The lower infiltration capacity associated with a 'moist' soil is thought to be partly responsible for greater runoff and therefore wash erosion. More recent studies (Palmer 1965, Wenzel 1970) have shown that the hydraulic conditions associated with a thin layer of water are such that the related turbulence is amplified and splash erosion is therefore enhanced.

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[3] Abbreviations (computer words) of the soil loss variables are shown in Table 5-3.

To study the pattern of change from 'dry' to 'wet' conditions, soil losses in dry runs are plotted against their wet run counterparts in Fig. 5-5. These data generally confirm established theory. However, there are a number of significant relationships that require discussion.

In the total loss cases tested at 10° and 30° slopes, the slopes of the best fitting equations are close to unity. For slope equal to 10°,

$$TOTALD = 0.65\ (TOTALW)^{0.95},\ R^2 = 0.94; \qquad (5.1)$$

and for slope at 30°,

$$TOTALD = 0.49\ (TOTALW)^{1.05},\ R^2 = 0.91. \qquad (5.2)$$

The similarity of these two equations is evident. For slope equal to 3°, the fitted equation for all data points is

$$TOTALD = 0.22\ (TOTALW)^{1.21},\ R^2 = 0.92. \qquad (5.3)$$

However, if data points from the prairie samples (Horizon = Ap) are eliminated, the resulting best fitting equation becomes

$$TOTALD = 0.61\ (TOTALW)^{0.96},\ R^2 = 0.92. \qquad (5.4)$$

This again is very similar to Equations 5.1 and 5.2.

The high R^2 values of Equations 5.1 to 5.4 suggest that the collected data have a high degree of internal consistency. The similarity of the coefficients in Equations 5.1, 5.2, and 5.4 indicates a general relationship between TOTALD and TOTALW despite the fact that there are differences in location, horizon, and landuse patterns.

The departure from this general relationship found in Equation 5.3 where prairie samples were included requires explanation. It is likely that because of the existence of surface detention (Section 5.4.2), the type of relationship between TOTALD and TOTALW is prescribed by the ponding effect. However, there is no doubt that the degree of internal consistency of data is equally high, as is suggested by the R^2 values in Equation 5.3.

In comparison to total loss, the degree of association in wash and splash loss data is not so strong (Fig. 5-6, 5-7). This tends to suggest that the separation of wash and splash is not complete. Lack of fit is also found for the small values in the wash loss data. This is probably related to greater measurement error at these levels. However, these small (in absolute terms) measurement errors are largely eliminated when wash loss is added to splash loss. These further suggest that at the level of measurement accuracy in these experiments, total loss is a more dependable index of soil erodibility than wash or splash loss alone.

Table 5-5 includes the best fitting equations for wash and splash loss. The equations for splash loss are close to those for total loss. For wash loss, R^2 for 10° slope samples dropped to 0.75 and the scatter diagram (Fig. 5-6b) shows a very strong 'clustering' effect.

Concentration of values in the lower ranges and probably higher measurement errors at these levels produce a regression equation that has a much smaller degree of freedom than the number of points on the diagram suggests (Croxton et al 1967). The slope of the line is therefore much less dependable.* However, if this is incorporated into a much larger diagram (Fig. 5-8a), the lack of fit disappears. This substantiates the contention that the lack of fit in Fig. 5-6b is due to sampling error. A similar plot for splash loss is presented for comparison (Fig. 5-8b).

For slopes at 3°, SPASHD is greater than SPASHW for SPASHD values greater than 710 g/m² (Fig. 5-7a). It can be seen that these high SPASHD values are associated with the prairie soils under cultivation. Because of the generally low aggregate stability of these soils (Table 5-8), splash took place rapidly in the dry run. Pavement effects due to the remaining less detachable particles reduced the splash rate during the wet run.

Another probable contributing factor is the effect of surface detention of rainwater in the wet run. Existence of surface detention water up to a critical thickness will reduce splash loss significantly (Palmer 1965). However, no measurement of the thickness of the water layer is available to verify this explanation, a point to be further discussed in Section 5.4.2

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* Take away the 4 highest points and 2 lowest points, and correlation is reduced to almost zero.

5.3.3 Variations in Splash-Wash Proportion

Of all the data sets analysed, 97 percent and 90 percent have more splash loss than wash loss in the dry and wet run respectively. This is contrary to the finding of Bryan (1974) where total splash loss is substantially lower than total wash loss for all sample groups. The likely explanation is the relative erodibility of the samples tested.[5] Bryan's (1974) samples are mostly from the plains area whilst in this study, mountains, foothills, and plains samples are represented. This difference would also suggest that the relative significance of wash and splash loss may be related to soil erodibility. Bryan (1974, Fig. 5-8) has already demonstrated a positive relationship between splash-wash ratio and percentage-weight WSA > 0.5 mm.

To test the hypothesis that splash-wash proportion is related to soil erodibility, the proportion of wash loss to total loss (both dry and wet runs) of each run was calculated, and their ratio x 100 percent was plotted against TOTALT for the three slope categories. These are presented in Fig. 5-9. In general, as total soil loss increases, the proportion of wash loss also increases though this situation is not apparent for the 10° samples during the dry run. This suggests a general relationship that increase in soil erodibility results from an increase in wash loss possibly with a concomitant increase in runoff. The lack of relationship for the low erodibility range is related to absence of runoff.

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[5] The slope angles used were different but even so slope is immaterial in this case.

However, these results do not show clearly whether there is any variation in the amount of increase in wash proportion between the dry and wet run. To show this pattern of change, the difference between dry run and wet run wash proportion is computed and plotted against TOTALT (Fig. 5-10).

For slopes at 3°, it can be observed that for TOTALT greater than 160 g/m², all samples have positive wash proportion values (Fig. 5-10c). It is interesting to observe that this threshold value is just about the lower limit of prairie samples shown in Fig. 6-1.

For slopes at 10°, such a pattern is not apparent (Fig. 5-10b). This is likely to be related to the small number of erodible soil samples tested at this slope angle.

For slopes at 30°, a complex relationship is suggested (Fig. 5-10a). For soils with a low erodibility, wash proportion does not change appreciably from the dry to the wet run but for soils of high erodibility, the amount of increase in the wash proportion is related to TOTALT. This further suggests that the increase in soil loss from the dry to the wet run is also a result of increasing wash loss.

5.4 Variations in Runoff

5.4.1 Within and Between Run Variations

Runoff data were adjusted as indicated in Section 5.2.2. Basic statistics are presented in Table 5-4. The data show a strong right-skew distribution. Use of log (to base 10) transformation produced an adequately normal distribution (Fig. 5-11) but this requires the elimination of those data sets having zero 'U-Rd' values.

The pioneer work of Horton (1933, 1945) has established the classical model of infiltration for barren soils. The infiltration rate is at its peak at the initial time and gradually decreases in time until a final infiltration rate is reached. An examination of the runoff data indicates that the final infiltration rate does not always appear within the two 30-min run periods and if it does appear, it is more likely to be within the wet than the dry run. Because of this variation, total runoff in the dry run depends largely on the slope of the infiltration curve, whilst in the wet run runoff amount is more likely to be a function of both the slope and the time prior to the occurrence of the final rate.

For between run variations, Fig. 5-12 shows the relationship between RUNOFD and RUNOFW at different slope angles. Generally runoff increases from dry to wet run. The presented significance of the best fitting equations are reasonably high, but clustering, particularly in the case with slopes at 10°, affects the regression results. In these cases, the significance of the equations are considerably reduced.

5.4.2 Pattern of Runoff Rating

Runoff rating curves are available for samples which produce a measurable amount of runoff, in other words samples with relatively low infiltration rates. Generally these curves approach the classical shapes described above. With higher runoff rates during wet runs, the final runoff level for the dry run is usually attained at the 10-minute mark during the wet run. Some typical examples are shown in Fig. 5-13.

High runoff is registered for the prairie samples that are or had been cultivated. In many cases, the amount is greater than 50 percent of the available rainfall. The classical curve shape is complicated by inflexion points usually in the middle of the dry run (Figs. 5-13a, 5-13b). This feature is likely to be related to surface detention of runoff water observed during the experiment. For some runs, the approximate time of occurrence of surface detention was recorded and noted in the diagrams. In each instance, initiation of surface water detention corresponds to the occurrence of the inflexion points in the infiltration curves. The first development of a surface detention system contributes to a rapid increase in runoff but once the system stabilizes, the rate of increase is retarded.

The origin of surface detention development is possibly related to both rapid transport of detached particles by wash and splash towards slope bases and similarly rapid compaction of surface soil layers by raindrop impact (Section 5.9). Incidentally, this development also explains why in the WAASHD-WAASHW plots, this group of sample tends to show a different distribution pattern. The absence of a linear relationship between RUNOFD and RUNOFW values of this groups of soils can then be accounted for.

High runoff is also recorded for samples tested at a 30° slope (Figs. 5-13c, 5-13d). Generally two patterns were observed. A first group yields a similar curve as found in the prairie samples. The rapid increase in runoff in the first 10 to 15 minutes, however, may not be associated with surface water detention. It is possible that the rapid rise in runoff rate is associated with saturation of the top few surface cm of soil but no quantitative data is available to test this hypothesis. Theoretically, however, such a cause cannot be distinguished from surface water detention because ponding cannot take place until the surface layer is saturated.

The second group shows the absence of any inflexion point until the final infiltration rate is reached (Figs. 5-13e, 5-13f). This group tends to associate with high dry run runoff. The cutoff rate is approximately 180 ml/min.

Low runoff rates are observed for most 10° slope samples, possibly because these are the relatively non-erodible rough pasture soils. Insufficient data are available to develop a definite pattern.

5.5 Aggregation

5.5.1 Aggregation and Soil Erodibility

It has been frequently reported in the literature that size and stability of aggregates are related to the resistance of the soil to erosion. Stable aggregates work in two ways to reduce erosion : (a) they resist dispersion by raindrop impact and (b) they maintain a relatively high rate of infiltration and thus reduce the amount of runoff.

Various aggregation indices were developed since the 1930's. However, a distinction should be made between those indices that were developed for application in crop-yield studies and those developed to index soil erodibility.[6] Although the indices tested in relation to crop yields (Schaller & Stockinger 1953, DeBoodt *et al* 1961, Conaway &

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[6] It should be noted that other erodibility indices had been developed which are based on various combinations of soil properties (Bryan 1968b).

Strickling 1962) are not directly relevant to soil erodibility, this related literature is useful in showing the relationship among the various indices.

Subsequent testing by correlating these indices with laboratory simulated soil loss have shown the superiority of some measure of percentage-weight water stable aggregates or WSA (Woodburn & Kochayn 1956, Adams *et al* 1958, Yamamoto & Anderson 1973) although a universally applicable index, if any, is yet to be developed (Bryan 1968b). But it has not been clarified which measure of WSA is best related to soil erodibility. The following discussion is an attempt to consider this problem from a rational point of view.

Basically each of these measures relates to one of the parameters in the aggregation size distribution curve.[7] 'Mean Weight Diameter' (Van Baval 1950) is the mean of the distribution. 'Geometric Mean Diameter' (Mazurak 1950) is the mean of the distribution under log transformation. Percentage-weight WSA greater than a given size is part of the area under the distribution curve and Percentage-weight WSA in between two threshold values is also part of the area under the curve. If different soils have similar distribution curves, i.e. the curves have similar shape, these measures should all be perfectly correlated among themselves. From this point of view there is no *a priori* reason to suggest any one of these measures to be more accurate.

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[7] This discussion assumes a consistent method of measuring aggregate size. It is recognized that different wetting methods lead to entirely different results.

However, in nature different samples have different aggregate size distribution curve shapes. Even for the same sample, the shape of the curve depends on the upper limit of aggregate size chosen. Thus, for soils with a larger number of finer aggregates, a lower threshold value (e.g.>0.5 mm) gives a better range of data and therefore could become a more significant measure. Geometric Mean Diameter will also be more significant than Mean Weight Diameter because it gives more weight to the finer aggregates. For the same samples, the upper limit of aggregate size chosen probably does not significantly affect the range of data reported. The fact that the smaller threshold values seem to be more significant in many instances (e.g. Yamamoto & Anderson 1973, Bryan 1974) may perhaps be explained by the method of wetting used. In these cases, the rapid immersion method used is reported to cause great disruption due to 'miniature explosions' of the aggregates because the entrapped air is under great pressure when water is drawn into the aggregate by capillary forces (Emerson & Grundy 1954). This can therefore produce an abundance of fine aggregates in the standard wet sieving technique (Yoder 1936).

5.5.2 Best Aggregation Index

Six indices were computed for the present study.

They include : Percentage-Weight WSA > 2.83 mm (PWSAG3), Percentage-Weight WSA > 2 mm (PWSAG2), Percentage-Weight WSA > 1 mm (PWSAG1), Percentage-Weight WSA > 0.5 mm (PWSAGH), Mean Weight Diameter (MWD), and Geometric Mean Diameter (GMD). The upper cutoff value of 4 mm was used in order to make data comparable to samples used for simulated rainfall study. As expected, these indices are highly intercorrelated (Table 5-6).

In order to select one single aggregation index for further study, the six indices were correlated with three soil loss measures : TOTALD, TOTALW, and TOTALT for three slope test conditions (Table 5-7). Transformed data were used because all six distributions are right-skewed. The four WSA indices have a root-normal distribution whilst MWD has a log-normal distribution. The GMD index is still right-skewed when log transformed. Use of the double-log transformation (McConnell 1966) produced a normal distribution.

Generally negative correlations are observed. They are significant at the 5 percent level. Other than three exceptions (PWSAG3 for slopes at 30°) there is a general increase in 'r' values from large to small WSA threshold values. The GMD index has higher 'r' values than the MWD. This suggests the dominance of fine aggregates. It can also be observed that variations in 'r' values among TOTALD, TOTALW, and TOTALT are small.

Overall, PWSAGH and GMD have the highest 'r' values. Since PWSAGH is easier to obtain and since it has been used for a similar study in Alberta (Bryan 1974), it was taken to be the most useful index of aggregate size in the present study. In view of the fact that they are highly correlated, use of either one probably would not make any difference in subsequent data analysis.

5.5.3 Aggregation Data

Subdivision of PWSAGH by physiographic zone, landuse types, and soil horizon is presented in Table 5-8. The mean and standard deviation of each category are also shown. It is apparent from this table that foothill soils are the best aggregated, followed by mountain and then prairie soils. A comparison of soils under grass in the three physiographic zones gives a similar ranking although this may be less convincing because sample sizes are small in the mountain and the prairies. The tendency for C horizon samples to be much less aggregated is also indicated. The fact that B horizon samples are generally better aggregated is probably related to higher sampling intensities in the 'disturbed' sites. Also field observations show that 'A' horizons are usually thin even on gentle slopes, particularly in the Stimson and Pekisko Creek area. This may be the result of past overgrazing leading to eroded 'A' horizons or in some areas the result of past clearing, leaving behind remnant Brown Wooded soils with thin A horizons. The development of strong subangular blocky structures in the B horizons may also contribute to better aggregation in these horizons.

For landuse effects, barren sites show poor aggregation, obviously because of loss in organic matter. In the foothills zone, parkland type of vegetation cover exists in small areas and these are classified as forest landuse. These samples show better aggregation than grassland soils but the results are not conclusive. Lack of a suitable sampling design precluded vigorous statistical testing of this difference. It is probable that under virgin conditions the foothills grassland soils would be much better aggregated than the forest 'B' horizon soils in the mountains but present data only show that they are marginally better aggregated.

By far the most significant effect of landuse is the reduction in soil aggregation due to cultivation. A rough comparison of the 'A' horizon soils in the Prairies shows a reduction of over 50 percent aggregation. Most likely reduction in aggregation is the result of the lowering of soil organic content as cultivation exposes the surface horizons to erosion.

5.6 Soil Organic Content

Previous studies have all demonstrated the inverse relationship between soil organic content and erodibility (Peele 1937b, Balci 1968, Bryan 1969). The main influence of organic matter content, however, appears to lie in its relationship to soil aggregation. As Browning (1937) observed, application of organic matter results in an increase in infiltration capacity, a decrease in the ease of dispersion of soil particles, and an increase in the number of large-sized aggregates, resulting in reduced erodibility. Meeuwig (1970) reported a possible adverse effect of high organic content on erodibility of sand-sized particles. This effect may be related to soil properties of water-repellency.

Data collected in this study are summarized in Table 5-9. Only organic carbon content is reported. Overall, foothill soils show the highest organic carbon content, followed by the prairie and mountain soils. The average 'A' horizon grassland soil in the foothills has an organic carbon content almost two times that of a grassland soil in the prairies and well over two times the organic carbon content of a cultivated prairie soil. The one mountain A horizon soil is located close to a 'peaty' area. Such areas are found in various parts of the Cataract Creek Basin but not enough is known to ascertain their origin.

Down profile decrease in organic carbon content is well illustrated by the collected data. The much higher organic carbon content of grassland soils compared to forest soils even in the B horizons is also suggested. This would imply that forest soil aggregates are more related to high clay content rather than high organic content. Reduction in organic carbon content due to cultivation in the prairies is not as great as would be expected possibly because of maintenance of fertility through chemical fertilization.

Relationship of organic carbon content to soil loss variables are shown in Table 5-10. Square-root transformation was used to normalize the distribution of organic content. Significant negative correlations (at 5 percent level) are established for all cases except for SPASHW at slopes of 30°. Bryan (1974) observed that organic carbon content is unrelated to total soil loss. Since his samples are mostly from the Alberta prairie areas, cultivated soils are grouped for this study and similar correlation coefficients computed (Table 5-10). The result is consistent with the finding of Bryan (1974). Whilst Bryan invoked the failure to distinguish colloidal humus and coarser vegetal fragments in the analytical technique employed, the technique adopted in this study (Section 4.7.3) tends to minimize such an error source.[8] The present analysis result is interpreted as either (a) an indication of a possible lack of correlation of prairie samples due to the small range of organic carbon content studied, or (b) an indication of the relative insignificant contribution of organic carbon content to aggregation for the prairie samples. This will be further discussed in Section 5.8.

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[8] Most coarse vegetal fragments were removed before the sample was ground to pass through the 0.5 mm sieve.

5.7 Soil Texture

5.7.1 Significance of Textural Separates

Apart from the fact that fine sand fractions tend to be more detachable by rain-splash (Ekern 1950, Mazurak & Mosher 1968, Farmer 1973), the influence of primary particles on erosion is not fully understood. This problem is perhaps developed from difficulties in isolating particle size variables and the fact that under field conditions, soils do not exist in their primary particle constituents except for the very coarse fractions.

If soils are aggregated, the finer fractions (e.g. > 10μ) contribute to the binding of the coarser ones, and therefore the relationship between soil loss and clay content is an indirect one. In the unaggregated case (mainly sand), fine sand is most detachable but coarse sand (e.g. > 2 mm) is likely to be more resistant and coarser particles may also have a protective effect on the underlying material. Thus, although a direct relationship between soil loss and sand content may be expected, linearity in the relationship cannot be taken for granted.

The above discussion assumes that organic content is held constant. However, it has been reported that for the same soil, both organic content and clay content may vary with aggregate size (Garcy 1954, Khan 1957). The smaller aggregates (e.g. < 0.5 mm) tend to contain a larger amount of clay and organic matter than the larger ones do. Thus the detailed interactions between colloidal clay and organic matter in aggregate formation and stabilization (Allison 1973) can be extremely complex and would require many laboratory experiments to unravel. Existing knowledge in this field is reviewed by Harris et al (1966), Allison (1968) and Baver et al (1972).

5.7.2 Texture Data

All texture data are plotted in Fig. 5-14 according to physiographic zone. Most samples belong to the loamy category but mountain soils are more sandy and foothill soils are generally more clayey. Such a pattern is also shown in Tables 5-11 & 5-12 where sand and clay fractions are tabulated according to physiographic zone, landuse, and soil horizon. The general textural classes of these soils may well be associated with their respective parent materials. Many mountain soils are residual in nature and soil profiles are usually not as well developed as in the plains. Foothills and to a large extent prairie soils are developed from glacial, lacustrine, and glacio-fluvial deposits. Since those parent materials vary greatly in their textural composition, any observed difference between textures of prairie and foothill soils cannot be explained in terms of differences in parent material. An examination of the individual data points indicate that the high clay content of foothill soils is in fact due to the presence of a number of samples from Spruce Ranching Section. These samples are developed from clay-rich tills and lacustrine deposits in this area.

Differentiation by horizon shows generally more sandy 'B' horizons while 'C' horizons can be very variable. A number of C horizon samples from barren sites in the mountains show extremely high sand content for bedrock is very close to the surface. Sampled forested B horizons do not show clay enrichment. This concurs with a general lack of good Bt horizon development according to field observations. Differentiation by landuse does not show any distinct pattern.

Relationship of clay and sand fractions to soil loss are shown in Table 5-10. Their significance varies with the group of soils tested, and erosion process (splash or wash erosion) under consideration. This will be further discussed in Section 5.9.

In aggregation analysis the amount of sand > 0.5 mm in the sample is determined for the sand-correction procedure described in Section 4.7.2. This provides data for an additional texture variable that covers the coarse sand range (0.5 to 4 mm).

5.8 Relationship of Clay and Organic Carbon Content to Aggregation

Baver (1935), in his classical study, reported the reciprocal ameliorating effect of organic matter and colloidal clay towards soil aggregation. Harris et al (1966), reviewed many subsequent studies and indicated abundant conflicting evidence. Since both clay and organic content influence soil erodibility via soil aggregation, an attempt is made here to evaluate their relative contributions in promoting and maintaining aggregation on the basis of statistical analysis results.

For the samples analysed in this study, sand fraction tends to be more significantly related to aggregate size than clay content but both are significant at the 1 percent level (Table 5-13). The general relationship established is as expected : sandy soils are associated with poor aggregation and the reverse is true for clayey soils. The fact that sandy soils are more significant may be explained by a higher sensitivity of the variable due to a wider range of data. Only clay content is further considered in this section.

Table 5-14 shows the interrelationship of these variables considered at three test slope categories. Clay content is significantly related to PWSAGH for samples tested at 10° and 30° but not organic content. For 3° slopes, organic carbon content is significant but not clay content. This latter result points to a possible differentiation of this interrelationship by landuse because the 3° slope group is known to be an heterogeneous sample (Section 5.3.1) and 53 percent of the samples are cultivated soils.

Classification of all samples according to landuse (Table 5-14) shows that clay content is significantly correlated with PWSAGH for grassland and forest soils, but not for soils from barren and cultivated sites. For organic carbon content, it is significantly related to cultivated and grassland soils but not forest soils. Of special note is the fact that organic carbon content is negatively correlated with PWSAGH for grassland soils (Fig. 5-15).

Without detailed experimental studies, it is very difficult to explain why the interrelationships among clay content, organic content, and aggregation should be as described above. It is hypothesized that the significance of organic carbon content varies with total organic content. For high organic content, increase in organic content has minimal effects on aggregation. This is shown by the negative relationship between PWSAGH and organic carbon content for grassland soils and the plotting in Fig. 5-15. The reverse relationship occurs at about 7.6 percent organic carbon content. When organic content is low, its effect is very variable, as shown by the relatively larger variability of PWSAGH at these organic carbon content levels in Fig. 5-15. The most significant effect would therefore be expected in the middle range of organic content. This is the case with prairie cultivated soils (Table 5-14).

To further clarify these interrelationships, all samples are grouped with respect to organic content. By this grouping, correlation between clay content and aggregate size is shown to increase to a level when organic content is around 7 to 8 percent (Table 5-16). The highest 'r' value obtained is 0.53 which is significant at the 0.1 percent level. Beyond this threshold range, the influence of clay drops again. On the other hand, grouping by clay content does not reveal any appreciable change in the relationship between organic carbon content and aggregation (Table 5-16).

These results indicate that for the samples analysed, the part played by organic content in promoting and maintaining aggregation varies with the level of organic content. The contribution of clay content, on the other hand, also depends on organic content, the highest significant relationship being within the middle range of organic content. This result agrees with suggestions made by Allison (1973) and Hartmann & DeBoodt (1974). It is also borne out by a study of regional aggregation data (Kemper & Koch 1965) in which organic matter and clay content are the two most important variables explaining the variations in aggregation, organic matter being the more significant.

5.9 Relation between Soil Loss Variables and Soil Properties

That several distinct processes : (a) raindrop splash, (b) unconcentrated wash, (c) concentrated wash, and (d) a mixed erosion in which entrainment is by raindrop splash and transport is by wash, are involved in water erosion (Lattanzi et al 1974, Bryan 1974), is not as widely appreciated as it should be. In the laboratory simulation situation, processes (a), (b), and (d) are more significant. Process (d) is difficult to isolate because of its mixed-mode nature. The following section attempts to highlight some aspects of erosion by raindrop splash and unconcentrated wash on the basis of statistical analysis results. Variations due to soil moisture status (dry and wet run conditions) will also be indicated. The basic problem with such interpretations is that significance of relationships can easily be affected by the range in soil types studied. However, when individual soil types are considered, sample size becomes much smaller and spurious correlations more probable. Also, the range of any given soil property may become too small to reveal significant relationships.

Correlation coefficients for soil properties versus soil loss variables divided into three slope categories are shown in Table 5-10. Similar correlation matrices for three soil types : mountain-forest B horizon, foothill-grassland A horizon, and prairies-cultivated Ap horizon were also computed.

With the exception of prairie cultivated soils, there is only very limited reduction in correlation between percentage-weight WSA > 0.5 mm (AGG) and soil loss parameters from dry to wet runs (Table 5-10). This suggests that dispersion of aggregates is not significant for most soils. This result agrees with general laboratory observation. It is therefore logical to expect little differentiation in 'r' values between wash and splash loss against AGG. The actual 'r' shows slightly higher values for splash loss in a few cases suggesting that dispersed aggregates are preferentially transported by wash erosion but the overall difference is very small. For cultivated soils, there is a significant reduction in 'r' values from dry to wet run, indicating significant dispersion of aggregates. For samples tested at 10°, AGG is not related to runoff both in the dry and wet runs, generally reflecting the high infiltration rates of these samples.

That sand fraction is more related to splash than wash loss is expected (Table 5-10). Such a relationship does not seem to vary from dry to wet run. It is significant to note that for cultivated soils, sand is negatively correlated with soil loss variables although the coefficients are not significant at the 5 percent level.

Generally, clay is slightly more related to splash loss than wash loss. For grassland A horizon soils tested at 30° slope, however, the reverse is true, and clay is then more related to wash than splash loss.

For cultivated soils, clay content is positively correlated with wash loss (significant at 5 percent level) but not splash loss (Table 5-10), showing that increase in clay content is associated with increase in soil loss due to wash erosion. This is very unusual and the only logical explanation is that either the amount of clay is not aggregated or if aggregated the aggregates are not water stable and therefore are dispersed early in the run. Since clay content is not significantly related to AGG (actually the relationship is an inverse one, Table 5-13), at least part of the clay present in these samples must be interpreted as unaggregated. The low degree of water stability of these aggregates (Table 5-8) suggests very rapid dispersion under raindrop action. Thus the higher the clay content, the more rapid is the reduction in infiltration, the development of surface water detention, and the higher the rate of runoff. This is also shown by the good correlation between clay content and runoff.

For these cultivated samples, if surface detention did not occur, splash loss should also be related to clay content. But since surface water detention is present in these cases, the amount of splash loss is at least partially governed by the thickness of water layer which is also variable through time. Thus splash loss is not related to clay content.

Organic content (OCC) is more significantly related to wash than splash loss for all three slope categories. However, such a relationship is not apparent for A horizon grassland soils tested at 10° and 30° (Table 5-10). In view of the non-linear relationship established between AGG and OCC (Fig. 5-15), such low correlations are expected. But this still does not explain why OCC is more related to wash than splash loss. Necessarily for samples tested at 30°, higher 'r' values for wash are related to the presence of 15 samples from barren sites. These soils contain different amounts of clay but are invariably of low organic content, and therefore generate a relatively large amount of runoff and hence wash loss under the test conditions. Within the same group the grassland A horizon soils have high organic content, but the aggregates managed to resist dispersion and maintain a high level of infiltration. Thus runoff is limited and hence little wash erosion occurs. The presence of these samples produced a large range in OCC and therefore more significant correlation despite the reversal of trend in the relationship for high organic content. For splash loss, presence of a larger proportion of coarse sand (0.5 - 4 mm) protects the less resistant particles underneath.

(Note the negative relationship between coarse sand and soil loss variables) Splash loss is therefore less significantly related to OCC. The same can be said of the group of samples tested at 10° but in this case the effect is much less pronounced because only one sample from barren soils is involved.

For cultivated soils, presence of organic matter reduces soil loss but it is not significantly related to soil loss variables because aggregates affected by organic content are easily dispersed under raindrop impact.

5.10 Bulk Density

Under identical degrees of compaction and structural conditions, bulk density (BD) should be a strict function of texture. For disturbed samples in the laboratory situation, this same relationship should be observable so that BD is only another way of expressing texture. The objective of testing for BD, therefore, is rather to provide a measure of the degree of departure of the laboratory test condition from the field situation.[9] Some additional data on change in BD and moisture from the dry to wet runs are also collected in the laboratory.

BD is significantly related to sand and clay content (at 0.1 percent) but it is much more strongly related to OCC

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[9] Obviously bulk density is not the only possible measure of this departure.

(Table 5-13). The latter relationship is explained by the association of well-aggregated samples to high organic content. BD is positively correlated with practically all soil loss parameters (Table 5-10). That it is generally more related to wash than splash loss is reasonable because a change in bulk density directly affects infiltration rates which influences wash more than splash loss.

Three samples were selected for test of changes in BD and moisture content. They represent three major soil types : mountain-forest B horizon (CN08), foothill-grassland Ah horizon (TC35), and prairies cultivated Ap horizon (WA04). All these samples were tested at the 30° slope. The laboratory procedure is identical to all other samples except that after each run samples in the soil pan are tested for BD and moisture content. A small aluminum container of about 50 cc in volume is gently pressed into the soil until its bottom is flush with the soil surface. Then the entire container is dug out and excess soil pared off with a sharp knife. The core is then oven-dried overnight at 105°C. The weight of sample and loss in weight gives the BD and moisture content respectively.

The results of these tests are shown in Table 5-17. Compaction of the sample by raindrop action is illustrated in CN08 and WA04. But for TC35, the grassland soil, density remains unchanged. This demonstrates the fact that for well-aggregated soils, resistance to compaction is strong.

BD for the first two soil types probably comes fairly close to field conditions in the wet runs but this is not true for the well-aggregated sample.

For all three types alike, the soil is practically saturated at the end of the first run. The moisture content remained unchanged in the third run. Between-sample variations are obviously related to texture differences.

5.11 Summary

It is evident from the presented soil loss data that there is a high degree of internal consistency in the data for between run variations, which also suggest good control for between sample variations. If variations in surface particle size distributions can be avoided, the Edmonton-pattern rainfall simulator can produce results that are highly reproducible.

Examination of these data also indicates that whilst splash erosion is dominant, samples of high erodibility tend to have higher wash loss proportion. This points to the possibility of a domination of wash erosion for soils of still higher erodibilities. This was found in Bryan's (1975) data which has a mean erodibility much higher than that of the present sample. As a corollory, if the tests were carried out at slope lengths longer than the present 30.5 cm, wash erosion will also become much more significant. Also, increase in soil loss from the dry to the wet run is primarily a result of increase in wash loss.

The development of surface detention appears vital for the explanation of variations in soil erodibility. The data suggest that dispersion of aggregates, choking of pore spaces by dispersed particles, and compaction by raindrop impact, all contribute to reduction in infiltration or increase in runoff and therefore total loss. It is not known what proportion of the increase in splash can be relegated to the presence of a thin water layer. For the erodible samples from the prairies, this effect cannot be separated from development of an erosion pavement due to removal of the more detachable particles in the dry run. It appears that the effect of the thin water layer is relatively small.

The study of soil properties reveals the significance of the relationships of texture, organic content, and aggregation to soil loss, and their inter-relations. The fact that organic content is more significant than clay content in promoting and maintaining aggregation is well borne out by the data. The implication is that use of the land, including both cultivation and grazing in the area, must lead to reduction in both organic content and aggregate stability. This is well demonstrated by the poor aggregation of samples from cultivated sites. For these samples, presence of clay has an adverse effect because under dispersed conditions, the clay particles very quickly clog the existing pores, leading to rapid runoff and erosion.

CHAPTER SIX

FACTORS AFFECTING LABORATORY SIMULATED SOIL LOSS

6.1 Introduction

The main purpose of this chapter is to present the statistical analysis results of all available laboratory data, and, in particular, to show the quantitative relationships among soil loss variables and factors affecting soil loss. According to the experimental design, these evaluations were organised to consider in turn the effects of soil properties, slope, and cover density. These are presented in Sections 6.3 to 6.5.

Since one of the objectives of this study is to test the applicability of laboratory data to field conditions, development of a laboratory prediction model is also considered in this chapter. This is treated in detail in Section 6.6.

6.1.1 Soil Loss Prediction Equations

Developed equations have been reviewed in Section 2.7. It suffices to be emphasized here that a dichotomy exists in the approaches to the development of these equations. Leopold et al (1964), called this the 'rational' versus the 'engineering' approach, whilst Amorocho & Hart (1964) referred to them as 'physical hydrology' and the 'parametric and stochastic hydrology' approach. Krumbein & Graybill (1965) suggest the equivalent of this distinction is between analytical and empirical methods of analysis. But in practice, as pointed out by Amorocho & Hart (1964), the two approaches have often been used in various combinations.

In this study, the empirical method is pursued to develop quantitative relationships among the variables studied. However, this will suffice only if a descriptive model is sought. To develop a predictive equation there are several facets of the model that must be examined. This is outlined by Draper & Smith (1966).

Basically, the established relationships must be checked against known theory. The important point is that these relationships should be capable of being interpreted physically. Secondly, the estimated parameters in the equation should be stable both in time and space, otherwise dummy variables have to be introduced to account for spatial and temporal variations. Lastly, any systematic lack of fit of available data to the proposed data should be accounted for. Implementation of the model certainly requires adequate testing of its applicability.

6.1.2 Variables Under Study

Under the controlled conditions in the laboratory, rainfall intensity and duration are held constant. Thus only three other 'independent' factors are studied : soil character, slope, and cover characteristics. Other external factors such as physiographic zone, landuse, and soil horizon are investigated separately in Section 6.2.

Of all the soil properties measured, percentage-weight WSA > 0.5 mm (AGG), organic carbon content (OCC), clay content (CLAY), sand content (SAND), and percent coarse sand 0.5 - 4 mm (CRSD) are considered. The amount of runoff as an index of infiltration rate (RUNOFD, RUNOFW, RUNOFT) is also studied. Silt content and laboratory bulk density are thought to be too closely related to other variables to be considered independent and are therefore excluded from the statistical analysis.

For the slope factor, only slope angle (SLOPE) is included. Slope length is held constant in the study. The cover factor is measured by percent bare ground (COVER). This is a measure of cover density as simulated by use of a plastic foam board (Section 4.6.4).

For the three runs : dry, wet, and wet with cover density simulation, splash loss was separated from wash loss. Also total loss for the dry and wet runs can be computed. Thus there are a total of twelve possible soil loss variables. These are shown in Table 5-3. Transformed variables are used for all analyses presented.

Statistical analyses in the present study were computed by package program *SPSS available as a public file in the IBM 360/67 computer at the University of Alberta.

6.1.3 Analysis Method and Procedure

Both for field and simulated conditions, many mutually interacting variables are involved in soil erosion. Thus to explain the variations in soil loss requires the application of multivariate analysis techniques. In this respect multiple regression analysis is a commonly acceptable technique because by the use of transformations, many complex mathematical relationships can be approximated by the linear model, and certainly the solutions chosen by this technique are such that the relationships between the dependent and each of the independent variables are weighed against the inter-relationships among the independent variables.

For the application of this model, however, a number of basic assumptions have to be met (Draper & Smith 1966, Kmenta 1971).[1] In brief :

(a) For the multiple linear regression model

$$Y = B_0 + B_1 X_1 + B_2 X_2 + \ldots\ldots + B_n X_n + \epsilon$$

ϵ is a normally distributed random variable with mean zero and variance σ^2. ϵ_i and ϵ_j are uncorrelated, $i \neq j$ and necessarily independent.

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[1] Too often geographers are carried away by the elegance of a given statistical technique so that the basic assumptions are forgotten, and thus use becomes abuse and the analysis results erroneous. Only very recently were these assumptions and other associated problems given the necessary emphasis in the geographical literature. See Poole & O'Farrell (1971), and Hauser (1974).

(b) The relationships between 'Y' and each of the independent variables 'X_i' are linear in the parameters of the specific functional form chosen.

(c) In order to apply Snedecor's 'F' and student 't' tests for significance estimation, the variables are necessarily normally distributed.

(d) The independent variables, X_i, are linearly independent of each other, that is absence of multicollinearity.

To satisfy these assumptions, each variable is suitably transformed to approximate the normal distribution (Appendix 5-2). To avoid the effect of serious multicollinearity, correlation matrices were checked. Only independent variables which have 'r' values of less than 0.7 are accepted.[2] Linearity of relationship was examined simply by plotting each independent variable with the dependent. Finally to test the validity of the assumptions concerning the error term 'ϵ', residual plots are examined to ensure the absence of regular patterns in these plots as outlined in Draper & Smith (1966 Chapter 3).

For the evaluation of quantitative relationships, the three factors : soil character, slope, and cover are considered. Three test slopes were used in the dry and wet runs. Thus for each slope category, only soil character varies. In this case the significance of the various soil variables can be evaluated for each slope category.

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[2] The level of acceptance is arbitrarily fixed.

Independent evaluation of the effect of slope is not available in this study. But since the effect of soil character is known from the above-mentioned analysis, the contribution of slope can be studied when all data are used as one group.

In the third run, cover density was simulated. The effect of cover density can then be evaluated. Further, if it can be assumed that the general test conditions of the second and third runs are similar, as was found in a comparable study (Bryan 1974), it may be possible to isolate the effect of cover density by computing a soil loss ratio between the second and the third run.

For development of a predictive model, overall significant variables representing the three basic factors are selected. The established relationships were then checked against existing theory to ensure the general applicability of the model.

6.2 Variables External to the Multiple Regression Model

Total loss for the dry and wet run is used to index soil erodibility. This variable is subdivided by slope, landuse, and physiographic zone and the data are presented in Fig. 6-1 and Table 6-1. Since the effect of slope has not been studied, comparson of soil loss variables is only valid when slopes are identical.

The most obvious result is the high loss for prairie samples followed by mountain samples. The foothills samples have the lowest loss. Soil loss variability also increases in the same direction. For slopes at 3°, prairie soils (which are mostly cultivated) are about ten times more erodible than foothill soils (which are mostly grassland soils) under identical test conditions (Table 6-1). The erodibility of mountain soils lie somewhere in between these two extremes.

Classification by landuse reaffirmed the very high erodibility of cultivated soils.. The relatively high erodibility of forested soils are also shown. Barren soils have very variable erodibility, probably related to the erodibility of their parent materials.

For slopes at 3°, the ten-fold difference in erodibility between samples under grassland and cultivation probably reflects more closely the influence of cultivation on soil erodibility (Fig. 6-1).[3] For slopes at 10°, the two cultivated soils tested show an erodibility up to fifty times that of grassland soils from the foothills. This appears to be a more realistic representation of differences in erodibility due to regional differentiation (mainly climate) plus the effect of cultivation.

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[3] The one sample WM10 shown in Table 6-1 under grass for prairie soils tested at 3° slope is not representative of virgin prairie conditions. The area was heavily grazed and much of the virgin top soil was removed.

6.3 Effect of Soil Properties

The basic data* (Appendix 5-1) were subdivided into three groups according to slope and multiple regression equations were computed using nine soil loss variables as dependent and other soil property variables as independent variables. Transformed data (Table 6-2) were used for all regression analysis. The 5% significance level was used as the cutoff point for accepting variables in the regression sets. The resulting 27 regression equations are tabulated in Table 6-3.

Aggregation, organic content, and runoff are the most significant variables while clay is significant for the 30° group and coarse sand for the 3° group. For all the cases studied, aggregation appears to be the best single predictor of soil loss. This result agrees with all previous findings and is consistent with the mechanics of erosion. A measure of aggregation obviously include the two basic soil characteristics : infiltration capacity and resistance to dispersion.

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* For the first two out of the 153 samples tested in the rainfall simulator, wash loss was not effectively separated from splash loss and runoff amounts were not recorded. These two samples were not further studied. Of the remaining 151 sets of available data, 3 sets (CC03, CC04, CN05) have extremely high sand and coarse sand content. In fact, these are the samples from highly eroded sites in Cataract Creek Basin, where most of the top 'soil' has been eroded but aggregation was found to be incompatably high. It is thought that the weathered sandstone fractions were broken down when dispered and therefore give very unrealistic results.

As was discussed in Section 5.8, the influence of organic content and clay content are basically interpreted as through that of soil aggregation. Since the aggregation index selected cannot possibly represent every single influence aggregation has on soil loss (in this case the index only measures Percentage-Weight WSA > 0.5 mm and stable aggregates resistant to dispersion under 'flood' wetting), it would be logical to expect that both organic content and clay content are also significant variables. The fact that the influence of clay is more dependent on organic content than vice versa (Section 5.8) is also borne out by the analysis. An interpretation suggested by laboratory observation is that with small amount of organic content, aggregates cemented by clay minerals are not as resistant as that due to organic content with small amounts of clay present. When both organic and clay contents are high, organic content tends to be better correlated with soil loss, implying a stronger influence on aggregation. Statistically, organic content is more significant because its relationship with aggregation is a non-linear one (Fig. 5-15).

The influence of runoff as an index of infiltration characteristically varies from wash to splash loss (Table 6-3). Wash loss is in fact very highly correlated with runoff (Table 5-10) because there is a marked distinction between the erodibility of samples with and those without runoff under the laboratory test conditions. On the other hand, only when infiltration rate is very low, i.e. significant amount of runoff, (as found in cases with slope equal to 30°) will splash loss become affected. The influence of coarse sand is difficult to assess because most soils tested have low coarse sand content. The fact that it is found to be more significant in the 30° slope cases is because the prairie soils usually have very low coarse sand content (<5%) and therefore when put into the same group with other soils of slightly higher coarse sand content but much lower erodibility, the protective effect of coarse sand becomes apparent. From _a priori_ reasoning, it would be expected that sand should be more significant for splash loss than wash loss. This hypothesis is only partially substantiated in the cases when slope is equal to 3°.

Differences between significance of variables in the wet and dry runs are only observed in the cases when slope is equal to 30° (Table 6-3). It has been established that dispersion of aggregates and selective erosion of particles of some samples in the 30° group have taken place in the wet run (Section 5.9), and therefore some changes in the significance of variables are expected. By the same token, a similar shift should be expected for soils in the 3° group but this is not observed. One possible reason is that the group of cultivated soils within this category have aggregates that are so unstable that most are dispersed in the early part of the dry run and therefore the shift is only manifest within the run but not between.

The total amount of variation of simulated soil loss explained by the selected variables also vary considerably (Table 6-3). The 3° group generally show higher percentages ranging from about 65 to 85 percent. The amount of variation is slightly lower in the 10° and 30° cases, with a larger range in the 10° group. This is probably related to the larger range of soil types tested at slopes of 3°.

The most outstanding variation between wash and splash loss is a decrease in amount of explained variation (R^2) in the splash loss from dry to wet run but where slight increase in wash loss occurs (Table 6-3). This is characteristic of all three groups although it is less so for the 10° group. For the same runs, wash loss is better explained than splash loss. The inclusion of the runoff variable (which from another point of view can be considered a process variable for wash erosion) probably indicates why wash loss is better explained. The increase in R^2 values from the dry to the wet run, is therefore likely to be related to an increased accuracy in estimating infiltration rate, which more than compensated for any changes in the other soil variables affecting erosion. On the other hand, with the absence of a similar process variable, slight changes in the soil character can drastically reduce the percentage of variation explained. Small changes are indicated in the 10° slope case (reduction from 0.68 to 0.61) and greater changes are suggested for the 3° and 30° slope cases.

Under this experimental design, soil properties are the only independent variables considered. However, at best these variables in combination only explain 80 to 85 percent of total variation in soil loss, even if soil variables not significant at the 5 percent level are included. The remaining 20 percent or so of the total variation are ascribed to experimental error that includes variability in rainfall input (Section 4.6.3) variability in surface particle size distribution (Section 5.11), modification of soil properties during test, and various sources of measurement errors associated with both the independent, and the dependent variables.

As might be expected, a similar relative significance of the soil properties variables is found in the other regression equations with slope or cover density, or both, incorporated into the list of independent variables (Tables 6-5, 6-7). But in these cases, the partial regression coefficients of the soil variables become considerably smaller.

6.4 Effect of Slope

Before the effect of slope can be studied, the form of the slope function has to be investigated. In the literature, tangent slope is most commonly used, particularly in agricultural research (Zingg 1940, Wischmeier & Smith 1962). Other functional forms used include sin θ, (Schumm 1956, Young 1972), sin θ cos θ, (Schumm *et al* 1970, DePloey 1972), and $\tan\theta/\sin^{0.3}\theta$ (Horton 1945). These functions, together with their log transforms are considered in the present study.

Sixth order partial correlation coefficients between three soil loss variables : total wash, total splash, and total loss and eight possible functional forms of slope were computed (Table 6-4). For all three soil loss variables, the differences among slope functions are small.[5] It thus appears that the choice of any one out of the nine makes very little difference. However, there is a great difference between their significance with respect to splash loss and wash loss. The effect of slope is very strong on wash loss but for splash loss the coefficient approaches zero, suggesting no relation at all. This will be further discussed below.

For the present purpose, tan θ is chosen as the slope function for further analysis because it has been very widely used, thus making comparison of results easier, and because it is marginally better correlated with total wash and total loss than other slope functions examined.[6]

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[5] This is the expected result because the difference among these functional forms for slope angles less than 30° is small for the three given slope angles.

Using the nine soil loss variables available for the dry and wet run as dependent variables and the soil variables plus tangent of slope angle as independent variables, multiple regression equations were computed (Table 6-5). The procedure used is exactly the same as that described in Section 6.3. Additional equations using log(tan θ) as the independent variable were also computed. These equations are also tabulated in Table 6-5.

The general behaviour of the soil variables are much the same as described in Section 6.3. Tan θ is a significant variable for all wash loss cases but not in all splash loss cases. Because splash loss constitutes generally a greater proportion of total loss, tan θ is also not significant in the total loss cases. Use of a log transformation does not change the established relationships.

Whilst the relationship between wash loss and slope is expected, the relationship between splash loss and slope is not. In order to explain this totally unexpected result, the following leads were pursued :

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[6] sinθcosθ appeared to be a better choice from a theoretical point of view. This will be considered in Section 6.6.3.

(a) linearity of relationships ;

(b) existing theory and empirical tests of the relationships between slope and soil loss ;

(c) grouping effects ;

(d) masking effect of soil variables ; and

(e) an alternative explanation.

(a) Since a slight nonlinear element exists (after transformation) for some of the soil variables (Figs. 6-2 to 6-7), it was suspected that there was an under-estimation of soil loss for 5 samples with the lowest total loss, perhaps as a result of rainfall variability. Therefore, three additional regression equations were computed with these five data sets eliminated (Table 6-5, Equations 6.5.11 - 6.5.13). However, apart from the introduction of one or two more variables into the regression set selected at the same significance level and some slight increase in explained variation of the dependent variable, these equations show that the differential effects of slope on wash and splash loss are not related to possible measurement errors involving these five samples.

(b) For wash loss, although the hydraulics of overland flow are still not fully known, enough knowledge has been accumulated to indicate that both the velocity of flow and surface erosion have a positive relationship with slope angle (Emmett 1970, Kilinc & Richardson 1973). However, for very short slopes (30.5 cm in the present study), the exponents involved should be much smaller although the general relationships would be expected to apply.

Rowlison & Martin (1971) examined the theory for splash loss (both detachment and transport) and indicated that splash erosion is related to slope in a functional form that is close to $\sin\theta\cos\theta$. By this relationship the amount of erosion due to raindrop splash would be maximum when slope is 45°. Thus, a positive relationship of slope and soil loss is expected within the range 0 to 30°.

Laboratory work by Shvebs (1968) and Mosley (1973) both examined this relationship. Shvebs reported that total splash loss (S) is a positive linear function of slope (θ) :

$$S \propto \theta$$

for slope of 0 to 11°. Mosley presented a scatter diagram which roughly shows the following relationship :

$$S = 2.0 + 0.33(\theta)$$

between total splash loss in grams and slope angle in degrees. The range of slope examined was 0° to 25°. In both cases, a 10 cm wide plot was used.

(c) To check for grouping effects, only samples from non-cultivated sites were considered. Three multiple regression equations were computed (Equations 6.5.14 - 6.5.17, Table 6-5) but they show results similar to the first three (Equations 6.5.7 - 6.5.9).

(d) Possible masking effect of soil variables is shown by the removal of the 22 cultivated samples from the data set. The regression equation computed from the remaining data sets (Equation 5.5.18, Table 6-5) shows a very weak relationship between slope and total loss and therefore it is unlikely that masking effect is a sufficient explanation.

(e) Existing theory does not stipulate the effect of the size of plot on splash loss. But it appears likely that as the size of the plot decreases, splash loss becomes more significant and an increasing proportion of the splashed particles are transported directly outside the sample pan. In other words, the proportion of splashed particles transported by surface wash decreases at the same time. Therefore, comparing results to the work of Shvebs (1968) and Mosley (1973) which involved a much smaller plot, it can be argued that where significant amounts of runoff took place, at least part of the effect of slope on wash loss can be interpreted to indicate slope effect on splash loss. A direct corollory of this argument is that as plot size increases, the effect of slope on splash loss decreases.

A more significant consideration is the theory elucidated by Rowlison & Martin (1971) which only considers the downslope component as transported soil since under laboratory test conditions, splashed particles were collected on all sides of the sample pan. It is not known how much effect this difference will have on the slope-splash loss relationship but it appears that the tendency is a dampening of this relationship.

Thus, whilst soil detachability by splash theoretically decreases with slope angle under the laboratory test conditions, soil transportability by splash only slightly increases with slope angle, probably much less than the 1.0 power of sinθ as suggested by theory. Hence, the overall possible relationship between splash loss and slope is either a weak positive one or there may be no relationship at all, or total splash loss remains essentially the same when slope is increased, except when at very high slope angles.

Within the framework of the present experimental design, it is impossible to totally verify the above postulates. But such an interpretation of the analysis results is tentatively adopted. An independent test of the effect of slope is required.

6.5 Effect of Cover

Previous studies have all suggested that the functional relationships between soil loss and percentage bare ground are either an exponential curve or a power function (Osborn 1954b, Meeuwig 1965, 1970). Since there is obvious reason to believe an equal amount of increase in cover to be more significant in reducing runoff and soil loss in the poorer cover range, the log transformation of the variable percentage bare ground was adopted. Later regression studies do show that use of this transformation eliminates curvilinear trends in the residual plots.

If it can be assumed that the general relationships among soil loss variables between the second and the third run do not change appreciably, as was suggested by previous studies (Bryan 1968b, 1974), the relationship between percentage bare ground and the ratio TV/TW may be an independent assessment of the effect of cover on soil loss. However when TV/TW is plotted against log of percent bare ground (Fig. 6-8) it was found that the amount of scatter is different from one cover percentage to another. For 5 percent bare ground, the scatter is very large, which may be attributed to variations in the amount of modification of soil surface characteristics from the second to the third run. Another way of presenting this data is to plot TV against TW for different percentages of bare ground (Fig. 6-9). The fit is generally good for percentage bare ground of 15 percent and 45 percent but is poor for 5 percent. It is interesting to note that the slope of the three curves decreases from 1.29 at 5 percent bare to 0.86 at 45 percent bare, suggesting that at about 36.5 percent bare, the slope of a hypothetical curve is 1.0 or TV = TW ?

For comparative purposes, the basic data (Appendix 5-1) is subdivided into three groups according to slope and for each group, three multiple regression equations were computed using wash loss, splash loss, and total loss as the dependent variables and soil variables and percentage bare ground as independent variables. Again the 5 percent significance level is used as the criterion to accept variables into the regression set. These are shown in Table 6-6.

Obviously when sample size is small, fewer soil variables can be accepted into the regression set. However, the effect of cover is paramount in every one of the nine cases studied. The other three significant variables are aggregate size, organic carbon content, and clay content. Overall, wash loss has low percentage of total variation explained, as would have been expected from the relatively small amount of wash loss in most cases. Another reason may be the absence of a 'runoff' variable. This variable was not recorded for the third run because there is no efficient way by which actual runoff can be separated from 'through flow' from the plastic foam sheet. The regression coefficients also show that the effect of cover is stronger in explaining splash loss than wash loss.

Variations in regression coefficients of cover with slope are small, but the coefficient tends to increase with slope for wash loss. For splash loss, the coefficient is highest at slopes of 10°. These suggest a certain amount of interaction between slope and cover but the precise pattern cannot be ascertained.

When all samples are taken as one group (Table 6-7) the soil variables become consistently more significant. Slope is significant for wash loss and splash loss but for splash loss the sign of the relationship is negative. This is true for both tan θ and log(tan θ). Since according to laboratory observations some surface water ponding took place on cultivated samples, these latter samples were removed and a separate group of regression equations computed (Table 6-7, Equations 6.7.9, 6.7.10). The result reiterates what was found in Section 6.4, that the negative relationships between splash loss and slope are more apparent than real. There is in fact no relationship between these two variables. The effect of cover shows very small difference between wash and splash loss.

6.6 Soil Loss Prediction

For predictive purposes, the analysis results cannot be applied directly because a descriptive model is necessarily empirical and accordingly only covariations of variables are assessed. But if prediction is the ultimate objective, then the model must specify some causal relationships (Lowry 1968) among the variables selected. This means a search of the correspondence of the empirical and the theoretical relationships is required. Also the boundary conditions of the relationships should be consistent with theory.

A suitable combination of independent variables will be selected. In most cases, coefficients used have to remain empirical because vigorous theory that stipulates precise causal relationships is yet to be developed. Only in a limited number of cases are there published results available for comparison.

6.6.1 Soil Parameter

Results of regression analyses show that aggregate size (G) and organic carbon content (C) are consistently the most influential soil variables. The only exception is runoff, but this latter variable is only significant for wash erosion. For prediction purposes, 'runoff' is a built-in process variable and would otherwise be not available unless the same rainfall simulator and the same rainfall intensity are used for testing. Thus this latter variable is not selected.

It has already been said that the influence of organic content on soil loss is exerted through aggregate size so that the inclusion of organic content seems to be unnecessary. However, the stability of aggregates finer than 0.5 mm is not measured by the variable AGG and it appears that the stability of these finer aggregates are closely related to organic content. Thus the significance of the two variables : aggregate size and organic content may be interpreted as relating to the stability of the coarser and finer aggregates, respectively. The combined effect of these two variables may be considered a measure of soil erodibility.

The use of square root transformations for both variables is purely empirical. It is simply one way to approximate linear functions rather than to imply any physical meaning although under some specified conditions, the effects of aggregation and organic content can diminish with an increase in their respective values. With the collection of more data, it may be possible to eliminate these transformations. The implied relationship according to analyses results is :

$$E_t \propto [e^{-(\alpha_g \sqrt{G} + \alpha_c \sqrt{C})}] \quad (6.1)$$

where 'E_t' is total soil loss, 'G' is percentage-weight WSA > 0.5 mm, 'C' is organic carbon content, and α_g and α_c empirical coefficients. This is a negative expotential function. When 'G' = 0 percent, 'E_t' is a large positive number. When 'G' is 100 percent, 'E_t' takes a small positive value. The same applies to 'C'. These boundary conditions are consistent with field and laboratory erosion conditions.

6.6.2 Cover Parameter

In the present case, the effect of cover appears rather simple. Since it is expected that increase in cover effects diminishes towards higher cover densities, the proposed relationship between soil loss and cover takes the form of a power function :

$$E_t \propto K^{\alpha_k} \qquad (6.2)$$

where 'K' expresses cover as percent of bare ground and α_k is an empirical coefficient. No comparable quantitative relationships have been published but available literature (Osborn 1954b, Meeuwig 1970) shows curves that approximate quadratic functions. This possible form of relationship cannot be evaluated because only three cover densities were studied.

According to the proposed relationship, $E_t = 0$ when $K = 0$. Under field conditions, a very small amount of loss (ΔE) is possible even when cover is complete (i.e. $K = 0$) but since in the laboratory situation 'E_t' should be zero if $K = 0$ and since in practice E is probably very small, it is felt that ΔE may be ignored and the proposed relationship is adequate for the present purpose.

6.6.3 Slope Parameter

The effect of slope on soil loss was found to vary from splash loss to wash loss. The analysis result on splash loss is probably not applicable to field conditions[7]. But for the purpose of developing a laboratory prediction equation, this result has to be entertained since it is realistic and is explicable in terms of erosional processes involved (Section 6.4).

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[7] An alternative model with splash loss correlation is discussed in Section 6.6.5.

In view of the varying effects of slope on splash and wash loss, two separate relationships are proposed. For wash loss,

$$E_t \propto (\tan 0)^{\alpha_s}$$

where 'θ' is slope angle in degrees and α_s an empirical constant. This is a power function suggesting that when slope = 0, there is no soil loss and when 'θ' is large, 'E_t' is a large positive number. These boundary conditions are valid within the slope range 0 to 30°. However for extrapolation to slope angles greater than 30°, the upper boundary condition is not valid. Horton (1945) has proposed a modification of the sin cos function :

$$E_t \propto \sin\theta / \tan^{0.3} \theta$$

as a suitable form of functional relationship between soil loss and slope. The $\sin\theta\cos\theta$ function will be used for later discussions of an alternative model.

For splash loss, it is assumed that under the laboratory test conditions, the amount of splash loss does not vary with slope. Thus, the slope function becomes :

$$E_t \propto W_p (\tan \theta)^{\alpha_s'} + (1 - W_p) \quad \text{or}$$

$$E_t \propto W_p (\tan^{\alpha_s'} \theta - 1) + 1 \qquad (6.3)$$

when 'W_p' is the proportion of wash to total loss. To predict 'W_p', a regression equation was computed using slope, aggregate size and organic content as the independent variables (Appendix 6-1). The form of the prediction equation is :

$$W_p = \alpha_o \tan^{\alpha_s'}\theta \times e^{-(\alpha_g'\sqrt{G} + \alpha_c'\sqrt{C})} \qquad (6.4)$$

where α_o, α_s', α_g', α_c' are empirical constants.

6.6.4 The Laboratory Prediction Equation

Since the effects of the soil, slope, and cover variables are multiplicative, Equations 5.1, 5.2, and 5.3 can be combined to give :

$$E_t \propto K^{\alpha_k} \times e^{-(\alpha_g\sqrt{G} + \alpha_c\sqrt{C})} \times \left[W_p\,(\tan^{\alpha_s}\theta - 1) + 1\right] \qquad (6.5)$$

or $$E_t = \alpha \times K^{\alpha_k} \times e^{-(\alpha_g\sqrt{G} + \alpha_c\sqrt{C})} \times \left[W_p\,(\tan^{\alpha_s}\theta - 1) + 1\right]$$

where $W_p = (\alpha_o \tan^{\alpha_s'}\theta) \times [e^{-(\alpha_g'\sqrt{G} + \alpha_c'\sqrt{C})}]$ and is an empirical constant.

The choice of suitable coefficients for the two soil variables is difficult because these coefficients are necessarily applicable to a limited range prescribed by a specific set of experimental conditions. For the sake of simplicity, a value of 0.2 is arbitrarily selected for both g and c. This value is well within the range found in the various descriptive equations.

For cover density, an exponent of 0.925 is selected since no comparable values of this exponent are published. Again this value is within the range given by Equations 6.7.1 - 6.7.8.

For tangent slope, previous field studies suggest an exponent of 1.4 (Zingg 1940). Under the laboratory test conditions, slope length is very short and therefore a value of 0.95 as given approximately by Equations 6.5.1, 6.5.4, and 6.5.7 appears in the right order of magnitude. Neal (1937) found an exponent of 0.7 in a laboratory experiment using a slope length of 3.7 m. It appears that the design of the Edmonton-pattern simulator tends to produce results that slightly overestimate the effect of slope.

For prediction of 'W_p', or proportion of wash to total loss, Equation 6.6 (Appendix 6-1) is used although the coefficients are rounded off to facilitate simpler computation.

There are no independent laboratory data available to test the validity of this prediction model. To illustrate the consistency of the presented arguments, this equation was applied to the set of 97 runs where cover density had been simulated (Fig. 6-10). The result is generally agreeable and about 80 percent of the soil loss variation is explained by this equation.

To investigate the existence of any systematic lack of fit of the proposed equation to data, a residual plot of fitted data in Fig. 6-10 is presented in Fig. 6-11. There is a general tendency for the variance of the residuals to decrease from small to large predicted values of soil loss. Apart from possibly minor violations of normality assumptions, the most probable cause of this lack of fit is the relatively small number of samples at the higher erodibility levels. Many of these samples are from the cultivated sites and they show higher consistency of relationship between soil loss and soil properties variables such as aggregate size and organic carbon content (Fig. 6-2 to 6-7).

6.6.5 An Alternative Model

Since it is known that the proportion of splash loss downslope (Sp) varies with the sine of slope angle :

$$Sp = 0.5 + \sin\theta \quad \text{(Ekern 1950)}$$

for 0 to 30 degrees slope, it is possible to introduce this correction to the available splash loss data. Admittedly there is no easy way by which the significance of such a correction can be evaluated, but it is considered that this corrected set of data and the alternative prediction model developed probably approximates more closely rainfall erosion under field conditions.

Accordingly, the new multiple regression equations were computed using corrected splash loss for dry run and wet run total splash loss as dependent variables, and the same soil properties and $\sin\theta\cos\theta$ as independent variables. The results are presented in Table 6-8 (Equations 6.8.1 - 6.8.3). In comparison with the uncorrected data, the computed regression coefficients for AGG, OCC, and CRSD are very similar to Equations 6.5.2, 6.5.5, and 6.5.8 in Table 6-5. With correction, slope becomes a significant variable at the 5 percent level. Between run variations in the exponent for $\sin\theta\cos\theta$ is relatively small, and as expected, there is a slight increase in the amount of explained variation in the dependent variables with the inclusion of one extra variable in the regression sets.

To investigate the effect of this correction on total soil loss, three other regression equations were computed (Equations 6.8.4 - 6.8.6). The same independent variables were included and dry run total loss, wet run total loss, and total loss are used as dependent variables. The result is similar to the last three equations. Slope becomes a significant variable with the exponent of $\sin\theta\cos\theta$ varying from 0.32 to 0.35. An alternative set using $\tan\theta$ instead of $\sin\theta\cos\theta$ as independent variable shows the exponent of $\tan\theta$ to vary from 0.29 to 0.32 (Table 6-8). This range of values suggests the much greater reduction in the significance of slope in comparison with the result of Neal's (1937) experiments. The effect of a very short slope is very strongly felt and the dominance of splash over wash loss for many soils is also a contributory factor to this reduction.

With the establishment of a new slope function :

$$E_C \propto (\sin\theta\cos\theta)^{\alpha_{sc}}$$

where α_{sc} is an empirical constant, the prediction equation (Equation 6.5) can be written as :

$$E_c \propto K^{\alpha_k} \times e^{-(\alpha_g \sqrt{G} + \alpha_c \sqrt{C})} \times (\sin\theta \cos\theta)^{\alpha_{sc}} \qquad (6.7)$$

where E_c is corrected soil loss and $\alpha_{sc} = 0.33$. This results in a much simplified model and one that is probably more applicable to the field situation. This latter assertion will be tested against collected field data in the next chapter.

6.7 Summary

Aggregate size (WSA > 0.5 mm) was found to be the best single predictor of simulated soil loss. Other significant factors include organic carbon content, runoff (infiltration), and texture. The dominance of aggregation over texture in affecting the erodibility of most soils can be adequately predicted by a combination of AGG and OCC. The physical interpretation adopted was that these two variables index the erodibility of the coarser and finer aggregates respectively.

Slope was found to be significantly related to wash loss but not splash loss. Two factors were presented to explain the lack of relationship between splash loss and slope : (a) the proportion of splashed particles collected outside the sample pan varies with the size of the pan; (b) existing theory that stipulates a relationship between splash loss and slope only considers particles transported downslope but laboratory experiments collect splashed particles in all directions.

A correction was therefore attempted by adopting the derivations of Ekern (1950) that the proportion of splashed particles varies directly with the sine of the slope. With correction, total loss was found to be significantly related to slope. The exponent of this relationship varies from 0.32 to 0.35.

Very significant results were found for the relationship between cover density and soil loss. The exponent of the established relationship is 0.925.

Deductive reasoning tends to suggest the following string of factors ordered according to their relative significance :

RAINFALL > COVER > SLOPE > SOIL.

Results of this study indicate in many cases a reversal of the order between slope and soil. It is uncertain, however, whether such a reversal is applicable to field situations where wash erosion may be much more significant.

By evaluating the relationships between soil loss and factors affecting soil loss and making appropriate theoretical justifications, a laboratory prediction model with five variables : cover density, Percentage-Weight WSA > 0.5 mm, organic carbon content, tangent slope, and wash proportion, was developed.

Using the slope correction mentioned above, an alternative model with four variables : cover density, Percentage-Weight WSA > 0.5 mm, organic carbon content, and sine-cosine of slope is presented. This model is more simplified and is thought to be more applicable to field situations.

CHAPTER SEVEN

FIELD MEASUREMENT OF SOIL EROSION

7.1 Introduction

This chapter is a review of all items of field data collected during the two field seasons of 1973 and 1974. These items, including soil loss, rainfall, cover density, soil moisture, soil bulk density and other related soil properties, are presented in Section 7.2. In Section 7.3 is shown all analysis results pertaining to these field data. Two temporal scales for these data, i.e., period and season, are considered. Both spatial and temporal variability of the analysis results are also examined. The soil loss data provide the basis for testing of the laboratory model developed in Section 6.6.

7.1.1 Erosion Plots

Thirty erosion plots of the design described in Section 3.2 were installed in the fall of 1972. Some details pertaining to these plots are presented in Table 7-1. Because of commitments to field mapping and soil sampling in the 1973 field season, these plots were only serviced for 1 to 3 times during this season.

Interim results from 1973 data indicate that in forested areas where natural vegetation is undisturbed, the amount of measurable soil loss is rather small. Also there are a few sites where cattle or other animal disturbance is too severe for practical maintenance of the plots. Therefore only 16 plots were maintained during the field season of 1974. Sampling dates were mainly determined by the occurrence of rainfall events; the dates usually fall in between storms and are spaced three to five weeks between each other during this latter season. However, because of various limitations (cattle and other animal disturbance; vandalism), only 68 sets of data (plot-periods) for 1974 and 22 sets for 1973 are considered valid for the statistical analysis to be presented in this chapter.

7.1.2 Data Evaluation

Soons (1971) has outlined some of the potential sources of error in a field study of this nature and most of them apply to the present investigation. There was little experimental control over the intensity and rate of operation of the erosional processes that took place over the plot areas, so just exactly what processes were involved can only be inferred by analysis and in comparison with laboratory results. The sealing of the junction between the plot and the trough remains a serious problem although whenever a poor seal was observed, the data set was rejected. In view of these difficulties, it should be emphasized that these collected data are best considered as measuring relative rates of erosion. Additional controls are required for extrapolation of data to larger areas.

7.1.3 Variables Studied

In this study, soil loss was determined by weighing the collected soil and some small portions of organic material for each period of measurement. The amounts are corrected for slope as for the laboratory data and are expressed in g/m^2.

Only rainfall amounts are used but it is thought that rainfall amounts should be somewhat related to rainfall intensity over a period of a few weeks in the area.[1] To show this relationship, meteorological data of the station at Calgary from 1961 to 1973 were used. Number of hours of rainfall exceeding 2.5 mm were plotted against monthly rainfall for the months May through August (Fig. 7-1). Obviously there are chances that over a period of four weeks the number of hours of relatively high intensity rainfall may deviate widely from the observed general relationship but this probability appears to be relatively small. In Fig. 7-1, all data points except three lie within a range where the number of hours of rainfall exceeding 2.5 mm can be predicted by a given monthly rainfall amount within ±2.5 hours.

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[1] Even if rainfall intensity data are available, it is still very difficult to devise an 'intensity index' that applies to 'period data' since for each period, more than one rainfall event occurred.

Perhaps because of insufficient data, variations in this general relationship are not shown from one month to another but according to Longley (1972), rainfall intensity should be the highest in July.

When two-months data (i.e. May + June and July + August) were used, there is a greater tendency for larger deviations from this relationship to occur for larger rainfall amounts (Fig. 7-1), suggesting that over a period of about nine weeks or longer such a relationship becomes rather insignificant. It is thought that these rainfall amount-intensity relationships are probably applicable to the foothills and plains areas (although the regional pattern indicates a generally lower intensity in the plains), but probably not to the mountain valleys where much lower intensities are prevalent (see Section 3.6.3).

Cover density was measured each time the plots were serviced but unlike soil loss and rainfall amount, it cannot be accumulated over a period of time. Thus it has to be assumed that the cover density over a period varies linearly and therefore the average of two measurements can be used to describe the density during the entire period defined by these two measurements. The final measurements were expressed as percentages of bare ground.

Other variables used include a number of soil properties analysed in the laboratory. These are :

percentage-weight WSA > 0.5 mm, percent sand, percent clay, percent organic carbon, and percent coarse sand, 0.5 to 4 mm. Field bulk density in g/cm^3 is also considered.

7.2 Description of Data

7.2.1 Soil Loss

All available sets of soil loss data are tabulated in Table 7-2 & 7-3. Because of differences in the length of snow-free period, there is a general tendency for the number of periods of measurement to decrease from the prairies to the mountains. This is clearly seen in the 1974 period data.

As would be expected, there are large spatial and temporal variations in the measured amount of loss. For the 1974 period data, temporal variation appears to be greater, especially for the prairie sites. As will be seen later this is closely related to actual occurrence of rainfall events although variations in cover density, particularly early in the season, may also have some influence. In 1974, soil loss ranges from a maximum of 48.4 g/m^2 for #W6 in Period 1 to a minimum of 0.5 g/m^2 for #T3 in Period 3 and 4. The maximum recorded, however, is 167.4 g/m^2 for #T4 from July to October 1973.

Total season soil loss (Table 7-11) varies from 3 - 8 g/m^2 for fully forested sites in the mountains, to 1 - 21 g/m^2 for the foothill sites unaffected by partial clipping of vegetation cover, and to 5 - 99 g/m² for the prairie plots.

Spatial variability, on the other hand, seems to be less pronounced especially in the foothills zone. This may generally reflect regional patterns of soil erodibility. However, variability among individual sites is large, probably as a result of differences in cover density and rainfall.

7.2.2 Rainfall

Despite the establishment of raingauges and rain-collectors in practically all plot sites, (except in those forested areas where measurement of rainfall can be an extremely involved problem (Geiger 1965)), there are some cases where gaps occur in the data either because of gauge disturbance or because the data are suspect. In these cases, readings from close-by meteorological stations are used to estimate the missing values or rectify suspected readings. However, where such stations do not exist, such as for #W5 in Period 1, 1974, no rainfall data are available at all.

One associated problem in this area is the proportion of precipitation falling as snow (Section 2.6.2). Since snowfall in the spring or early fall may melt rapidly, there is no way by which this proportion can be measured unless on-site measurements are made during snowfall. In these cases the proportion at the plot sites is taken to be the same as that found in close-by meteorological stations. All available rainfall data are tabulated in Table 7-2 & 7-4.

To illustrate the amount of deviation of rainfall pattern during the study period from normal conditions, a table was prepared comparing monthly precipitation of 1973 and 1974 summer to the normal amounts for the stations Gleichen, Pekisko, Turner Valley, and Kananaskis (Table 7-5).

The data suggest that 1973 field season was relatively dry. Spring was close to normal but summer was dry. August rainfall was above normal; a storm on August 2 in Turner Valley area recorded 56 mm in 24 hours.

For 1974, a wet spring was evident in all stations. Summer was dry but above average precipitation was recorded for late summer and early fall for the foothills. This possibly applies to the mountain areas too.

To describe in greater detail the meteorological events that took place during this period, daily precipitation was plotted for selected stations (Fig. 7-2). In West Arrowwood Basin (stations 'Herronton East', 'Mossleigh', and 'Blackie North'), two major storms : April 26 and August 12 occurred during the period. Storr (Per. Comm.) suggested that the April 26 storm was of an intensity that probably has a return period of 20 to 25 years.[2] Many stations recorded over 75 mm precipitation and the maximum exceeded 100 mm in 24 hours. A trip was made to this area on April 25 and the plots were serviced so that erosion data for the first period of the season include the effect of this severe storm. This gives some indication of the maximum possible rates under the existing conditions. It is unfortunate that by April 26 the storm had already started and there was no time to service the plots in the other basins. The intensity of the August 12 storm is much lower and just over 25 mm of rainfall in 24 hrs was recorded at Mossleigh. Other storms in the field season were of low intensity.

In the Pekisko and Three Point Creek Basins (Figs. 7-2d to 7-2f), there is a considerable amount of spatial variability in the occurrence of precipitation. The April 26 storm was missed and, apart from that, only the August 11/12 storm is of relatively high intensity. July was very dry and for almost four weeks, from mid-July to early August, there was no trace of rain at Pekisko. A similar situation occurred at Turner Valley and at Millarville.

A comparison of the Prairie and Foothills station records shows a general correspondence from spring to summer. Only in late summer and early fall are higher frequencies of relatively more intense rainfall in the foothills found.

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[2] The actual short term intensities for this storm at the sites are not known. At Lethbridge, about 85 km south of West Arrowwood Basin, the recorded maximum intensity for this storm was 18.3 mm/hr for 15 min., 17.8 mm/hr for 30 min., and 11.7 mm/hr for 1 hr. At Vauxhall, 90 km to the east, the respective readings were 48.8, 35.6, and 25.5 mm/hr.

The Cataract Creek records are biased because these stations are located in highlands and therefore probably do not truly reflect the meteorological conditions of the basin during this period (Figs. 7-2g to 7-2h). However, the records show the absence of high intensity events during the entire period. For these stations, and likely for lower elevation areas in the basin, precipitation during the season can be in the form of snow. For instance, precipitation on August 11 and 12 was the major meteorological event of the period and of the total 45 mm collected on the two days at Hailstone Butte, almost 40 percent fell as snow.

7.2.3 Cover Density

Only very limited cover density data for the period of study are available (Table 7-2 & 7-6). Selected records for 1974 are shown in Fig. 7-3. Field observations generally indicate that cover density is poor immediately after snowmelt and gradually improves with the onset of the warmer season. This observation is reflected in the cover density records. The peak bare ground conditions generally occur in the April-May period for the prairie sites and in early May for the foothills sites. Cover densities in mid and late summer are very variable, perhaps more related to variability in the individual site conditions.

For the purpose of studying a wider range of cover density conditions, the better covered sites were clipped of part of their vegetation during mid-summer 1974. But the resultant variability in density of the July-September period is comparable to other sites where surface vegetation was undisturbed.

This problem of seasonal variability in cover density appears to have received little attention in geomorphological studies of erosion as compared to agricultural research. Under the existing field conditions snow cover of the previous winter flattens most types of herbaceous cover. In the early spring, when melting starts, temperatures are too low for growth to take place whilst grass is killed by frequently occurring spring frosts. Since moisture is generally not a limiting factor at this time of the year, growth will begin with the onset of warmer weather. This onset is likely to be earlier in the plains than in the foothills though slope and aspect may create important local variations.

Well into the summer, availability of moisture is more likely to be the limiting factor, and growth tends to be more varied in response to rainfall conditions even for the same soil type and similar site conditions.

7.2.4 Soil Moisture

Soil moisture samples were collected each time the plot sites were visited. But, as with cover density, such values cannot be accumulated over a period of time. For this reason, no soil moisture variable was used in subsequent analysis. All available moisture data are presented in Table 7-7, with each value representing a mean of five subsamples.

Because soil moisture is very variable over time, the data cannot be used to interpret adequately the general seasonal pattern of moisture change in the study area. To describe this pattern, a simulation technique developed by Thornthwaite and Mather (1957) was employed.

By this technique, mean daily temperature and amount of precipitation were used to simulate soil moisture balance.[3] Because only a small number of meteorological stations in the area have daily temperature readings, the moisture content of one plot site in the prairies and three in the foothills were simulated. The meteorological records in the Cataract Basin are not considered directly applicable to the plot sites. As the four selected stations lie 1 to 5 km from the plot sites, the simulated pattern must be treated with considerable caution. They probably only indicate general patterns within the period. The simulation results are plotted in Fig. 7-2 along with the measured moisture content.

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[3] A Fortran program written by Yoshioka (Stone et al 1971) was used for the present simulation study. Input data include : daily maximum and minimum temperature; daily precipitation; mean monthly temperature and latitude of the station to compute heat index for the station; water holding capacity of the soil; fraction of available gravitational water on any day held for later percolation; and soil moisture content at the beginning of computation. Since water holding capacity and fraction of available gravitational water under field conditions are not known, these two parameters were manipulated until the simulated pattern approximately fits measured soil moisture content.

The goodness of fit of observed and simulated moisture content is satisfactory except for the readings immediately after the August 11/12 storm. It is possible that this storm had a particularly variable spatial pattern of rainfall distribution but the coincidence of the results for three out of the four cases studied suggests that the entire batch of soil moisture samples might have been affected by prolonged storage prior to analysis.

In the West Arrowwood Basin, snow-melt occurred in early April. Moisture content was reduced to about 15 percent when the April 26 storm occurred (Fig. 7-2c). Subsequent precipitation fell on increasingly drier soil through May and June, so that soil moisture was very low during July and August except immediately after storms. The August 12 storm fell on very dry soil. The data indicate that moisture contents did not rise again until fairly late in the fall.

Despite differences in the precipitation pattern, the overall moisture content changes within the period is similar for Pekisko Creek and Three Point Creek basins (Figs. 7-2d to 7-2f). The pattern from May to July is similar to that found in West Arrowwood Basin except that precipitation tends to be higher for the foothills basins in May and gives, therefore, moister soils. The August 11/12 storm again fell on very dry soil in this area but rainfall in late May and September is heavier in these basins and therefore soils have a higher moisture content than in the prairies.

7.2.5 Bulk Density

Although no data on temporal variations in bulk density are available, it is assumed that the spatial component is much greater than the temporal one.* Bulk density is basically a reflection of the amount of pore spaces in the soil and it should be closely related to soil structure and depth which vary with soil horizon. However, different types of landuse can cause differences in compaction. The data generally show that except for site #W1, the prairie soils have the highest densities, ranging from 1.2 to 1.3 g/c³ (Table 7-8). The well-aggregated soils at the foothills sites (namely #P4 & #T3) have the lowest values (0.9 to 1.0 g/c³). Site #C4 from the slumping scar also has high bulk density value but it is more due to the presence of stones in the sample than compaction.

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* Frost heaving is probably the most significant process affecting temporal variations in bulk density. The magnitude of this source of error is not known but all samples were taken in late summer to ensure comparability.

Since there is no easy way by which soil bulk density under virgin conditions at the sample sites can be estimated, laboratory data (measured as described in Section 3.7.4) was used for this purpose. When this is plotted against field data, two groups of soils are immediately apparent (Fig. 7-4). The prairie sites (excluding #W1) together with #P2 have relatively low densities in the laboratory but high densities in the field. This is taken to be an indication of soil compaction mainly by animals. The rest of the samples have variable field densities, which are very well accounted for by their laboratory density values, and are considered non-compacted. For the first group of sites, the poorer relationship lends support to the argument that these sites have undergone varying degrees of compaction. The agreement of this division with the known history of the land is generally good but it must be understood that a particular site in a generally grazed area can be bypassed by animals because of various reasons such as accessibility and therefore could remain uncompacted since grazing began.

However, the graph showing the pattern for non-compacted soils is difficult to interpret. One possible interpretation is that for sandy soils aggregation tends to be poor and therefore reduction due to laboratory handling is relatively small for non-compacted soils. For better aggregated soils, which have relatively lower field densities, breakdown of soil clods produces aggregates that have more unit volume pore space, and may explain the greater reduction from field to laboratory density.

7.2.6 Other Soil Properties

Of all the other soil properties studied, soil aggregation is probably the most variable with respect to time. Most published works indicate that a snow cover over the winter is conducive to the development of aggregates (Anderson & Wenhardt 1966, Anderson & Bisal 1969) but if chinook winds remove the protective snow cover, freeze-drying will occur producing disaggregation (Hinman & Bisal 1968, Anderson & Bisal 1969). During the warm summer season, cycles of wetting and drying tend to increase aggregation (Sillanpaa & Webber 1961).

In the present study, sampling cannot be completed within less than two months and invariably some temporal variations may affect the data. However, use of period data probably eliminates much of the between-period variation in aggregation and therefore no attempt was made to measure temporal variations of these properties.

Soil aggregation, along with other soil properties data[5] are presented in Table 7-8. The general pattern of spatial variability conforms to larger data sets discussed in Chapter 5 but it can be seen that at least some of the results tend to reflect local variations in site conditions.

7.3 Statistical Analysis of Field Data

All measured variables are used in the multiple regression analysis described in this section. These include soil loss, rainfall amount, percent bare ground, percentage-weight WSA > 0.5 mm, percent organic carbon, percent sand, percent clay, percent coarse sand (0.5 - 4 mm), field bulk density, and slope angle.

Logarithmic transformations of soil loss, percent bare ground, and rainfall amount are used. A double-log transformation of soil loss was found necessary, probably because of the inclusion of much higher soil loss due to the April 27/28 storm of 1974. The log sine-cosine slope function was adopted.

Using the same stepwise regression technique as outlined in Section 5.1.3, soil loss is taken to be the dependent variable and all other variables independent variables, entered one at a time. The cutoff significance level is set at 5 percent.

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[5] For the plot site samples, duplicate subsamples were analysed to ensure higher accuracy of data

Available data were analysed at two different time scales. The 1974 data were collected at intervals of about three to five weeks and therefore constitute a set of short-term data, to be referred to as plot-period data. The 1973 data are mostly in intervals of over two months. Instead of using two month periods, all data were combined for each plot per field season. These, together with combined 1974 data, constitute the plot-season data set.

7.3.1 Plot-Period Data

For 1974, 68 complete sets of plot-period data are available. However, only 63 were used in this analysis because Plots #T1 and #T8 are under the influence of a forest cover and no adequate data are available to indicate the actual amount of rainfall at these sites. Therefore these five sets of data were excluded from the statistical analysis. Correlation coefficients among the variables used in this analysis are shown in Table 7-9.

Among all variables used, rainfall amount and cover density are the best related to soil loss. For the soil property variables, bulk density and organic carbon content appear most significant. Slope angle, however, appears to be unrelated to soil loss. It can also be seen that many soil variables are intercorrelated (Table 7-9), the highest coefficient being -0.70 between bulk density and aggregate size.

Regression results are shown in Table 7-10. Both rainfall amount and percent bare ground are the most significant contributors to the explanation of variations in soil loss in all regression equations. Their regression coefficients appear to be stable. For soil properties, different variables were selected in different equations but they achieve similar results. This suggests the interdependence of the soil variables. The significant ones include aggregate size, organic carbon content, bulk density, and clay content. Slope is not a significant variable in any equation.

Because rainfall and cover density are the only two independent variables that show both spatial and temporal variations, their dominance in all regression equations are expected. The significance of rainfall amount implies that the assumption concerning its relationship with rainfall intensity is at least partially substantiated.

For the other variables, it was assumed that they remain unchanged on the temporal scale and therefore have a smaller 'degree of freedom' than the number of plot-period data sets suggests. Given the small degree of freedom, it would be difficult to sort out the relative significance of these variables (because of multi-collinearity).[6] The analysis results are therefore interpreted to suggest the significance of the soil factor. That different variables are accepted in different equations should be considered a result of the small sample size available.

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[6] A comparison with similar data for a larger sample size already presented indicates the increase in the degree of independence among variables with sample size.

The fact that slope is not a significant factor is unexpected. Possibly the lack of relationship is due to the masking effect or collinearity with other more significant variables. Alternatively if rainsplash rather than sheetwash is the dominant erosional process, the proportion of splashed particles downslope will increase with slope angle. Since the outer edge of the trough is located at a fixed distance from the lip of the plot, the amount of undercatch will increase with slope angle. However, it is thought that this effect should be fairly small. This lack of relationship will be further discussed in Section 7.3.2.

Although only about 50 percent of the total variation in soil loss is explained, these R^2 values (Table 7-10) are interpreted as very significant results. It is obvious that the amount of unexplained variation should be ascribed to (a) measurement errors discussed in Section 7.1.2, and (b) soil moisture content and rainfall intensity, the effects of which are known in relative terms but not considered in the regression analysis.

The traditional use of the plot technique to study treatment effects prohibit any extensive comparison of results. Soons (1971) in New Zealand (already reviewed) used a large number of independent variables but the amount of explained variation is at best comparable to the amount in the present study.

7.3.2 Spatial Variability

Since the plot data were collected from three different physiographic zones, subdivision of the data may throw light on possible spatial variations in the established relationships. Because too few data from the mountain plots are available, only three subgroups are studied : foothills plots, prairie plots, and foothills + prairie plots. The analysis results for the 1974 data set are presented in Table 7-10.

For the foothills, the results are similar to those of the total sample (Equation 7.10.7). The lack of more significant variables other than rainfall amount and percent bare ground suggests the similarity of soils in the prairie plots (Equation 7.10.8). The inclusion of data for a major storm (April 27/28) may also have suppressed the effects of the soil variables.

The results for the third set of data : prairie + foothills plots, show the inclusion of a very significant slope variable in the regression set. However, as the regression coefficient is negative (Equation 7.10.6), a decrease in soil loss with increase in slope angle is suggested. The partial correlation between slope and soil loss (with rainfall amount, percent bare ground, and percentage-weight WSA > 0.5 mm controlled for) is shown in Fig. 7-5.

It can be seen from this figure that the significance of the slope variable is the result of juxtaposing a group of prairie samples with a relatively narrow slope range but high erodibility together with the foothills samples which have a wider range in slope but relatively low erodibility. Since aggregate size is controlled, the figure has to be interpreted so as to illustrate that aggregation alone is insufficient to explain the variations in erodibility but at the same time other soil variables cannot enter the regression set because of collinearity. The inclusion of a very intense storm for the prairie samples may also have raised the (negative) significance of the slope variable. The fact that slope is not a significant variable even in the foothills subgroup where a larger slope range was used strengthens considerably the arguments presented above.

7.3.3 Temporal Variability

Because average storm characteristics tend to vary from late spring-early summer to mid and late summer in Alberta (Reinelt 1970, Longley 1972), subdivision of the data pertaining to different periods may show possible temporal variabilities in the established relationships. Only two periods, late April to mid-June and mid-June to

September, 1974, are considered. The multiple regression procedure was repeated and resulting regression equations are shown in Table 7-9.

These equations show that in the second period, the effect of rainfall and the amount of explained variation in soil loss are considerably reduced. This is related to the absence of high intensity storms during the second period. Compared to the total set of data the regression coefficient for the soil variables, percent clay and aggregate size, shows slightly higher values, suggesting that some minor variations in soil characteristics are not explained when the two periods are considered as one. The effects of cover and slope are consistent with previous findings.

7.3.4 Plot-Season Data

All told, 29 sets of season data for 1973 and 1974 are available. These, together with total rainfall and mean cover density, are presented in Table 7-11. Correlation coefficients among the variables used are shown in Table 7-12. Among all variables, cover density and bulk density are the most significantly related to soil loss. All other variables, including rainfall, are not significant.

Using the same procedure for multiple regression analysis, soil loss was entered as the dependent variable and all other variables as independent variables. The result (Table 7-10) reaffirms the significance of cover and bulk density. Rainfall amount, however, was also included in the regression set at the 5 percent level. Total amount of soil loss variation explained is 56.5 percent, an amount comparable to previous results using plot-period data.

The adopted interpretation of these results is similar to the plot-period cases. Use of longer periods should reduce the significance of rainfall amount but this may be partially compensated for by the use of a large range in period length : 2 to 6 months' data.

It is not known why the effect of soil variables should be smaller than the case with period data, because as temporal variation is reduced, the between-plot variations which is closely related to soil properties, should become prominent. It seems that this reduction in the soil effect is related to an increase in the influence of cover density ('r' between cover density and soil loss changes from 0.53 to 0.64).

7.4 Summary and Discussions

In view of the relatively large amount of uncontrolled sources of error, an explanation of about 50 to 55 percent of total variation in soil loss by the variables selected is taken to be a very significant result. However, since erosional processes were not actually observed in the field, it can only be inferred from laboratory simulation results that rainsplash is the dominant erosional process during most rainfall events. Approach to field capacity appears to occur only during late spring in most of the sites studied and therefore wash erosion is confined to this time of the year or perhaps during very heavy storms in the summer. Therefore, the highest rainfall erosion hazard for these areas occurs during the period immediately following snowmelt, or for a considerably longer period if cool and/or wet weather persists.

The presented data demonstrate the overall significance of cover and rainfall factors in explaining soil loss variations. Compared to the results of Campbell (1970), Soons (1971), it is evident that spatial and temporal variations in cover density play a vital role, and need to be given greater emphasis in erosion studies. In view of varying relationships between rainfall intensity and rainfall energy in areas of high relative relief,[7] it is doubtful whether refinements in measures of rainfall erosivity such as found in the use of many rainfall variables (Soons 1971) would ever help to explain a greater amount of variation in soil loss than rainfall amount alone. Also, this problem of how to measure precisely natural rainfall erosivity, in addition to the difficulty in determining the accuracy of measurements of soil loss in small plot studies, probably limit any possible improvement in explaining soil loss. Rainfall simulation where rainfall erosivity is controlled appears to be the only alternative.

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[7] The work of Wischmeier & Smith (1958) was only found applicable to the agricultural areas in Central and Eastern United States

Because of the small amount of data available, and limitations of the experimental design, no conclusive statement can be made concerning the precise effects of soil and slope variables. In the plot-period data set, a number of soil variables : aggregate size, organic carbon content, bulk density, and clay content were found to be significant. Although the relative significance of variables varies, these are the same significant variables[a] found in the laboratory. Bulk Density is the only significant variable in the plot-season data.

Slope was not significantly related to soil loss but this result is misleading because in the multiple regression analyses attempted, cover density and rainfall effects are very strong and slope effects may be masked. Meeuwig (1971) found in a field rainfall simulation study that the effect of slope decreases sharply with increase in cover density. The slope of the relationship becomes very gentle when cover density is greater than 75 percent. Since most of the plot sites in the present study have very high cover densities, it is quite possible that such a weak relationship is not revealed.

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[a] Except for bulk density which was reproduced in the laboratory

CHAPTER EIGHT

SOIL ERODIBILITY & REGIONAL EROSION POTENTIAL

8.1 Introduction

The purpose of this chapter is to compare field and laboratory results concerning (a) soil erodibility, (b) other erosion factors, and (c) erosion potential. The laboratory model established in Section 6.6 is applied to the conditions under which field erosion took place and the results tested against the observed soil loss in the field.

A positive result of this test will partially confirm the relevance of the laboratory test procedures to comparable field situations. The laboratory data are then generalized on an areal basis to cover all the 17 units mapped in the field.

Since little is known about the distribution of soil erodibility characteristics in large areas in the mountains and foothills, further generalization is impracticable. As an alternative, other information such as rainfall intensity, landuse, and sediment yield in the area were collated and in conjunction with the erodibility and erosion potential data from the 17 units studied, some tentative conclusions were drawn as to the regional pattern of erosion potential and possibly its relation to sediment yield.

8.2 Soil Erodibility

8.2.1 Laboratory Data

Two different relations between slope and laboratory simulated soil loss, corresponding to the splash fraction being corrected or uncorrected (Section 6.6), were used to compute soil erodibility indices. In the first case, only the splash fraction that is transported downslope is considered soil loss according to the derivations of Ekern (1950). The 20° slope was used as reference slope for all samples. Soil erodibility (TOTALP) is computed by the formula[1] :

$$\text{TOTALP} = \text{CTT} \times (\sin 20^\circ \cos 20^\circ / \sin\theta \cos\theta)^{0.33} \qquad (8.1)$$

where CTT is corrected total loss (Section 6.6.5).

In the second case, all splashed particles are taken to be eroded soil. Since splash loss does not show significant correlation with slope, only wash loss is corrected. This alternative index of soil erodibility (TOTALQ) is found by :

$$\text{TOTALQ} = \text{SPASHT} + \text{WAASHT} \times (\tan 20^\circ / \tan\theta)^{0.937} \qquad (8.2)$$

(Table 6-5, Equation 6.5.7). The basic data are tabulated in Appendix 8.3. The overall range of data are from 13 to 3949 for TOTALQ and 10 to 2264 for TOTALP. Although the absolute values have very little meaning, this range is very comparable to that in Bryan's (1974) study.

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[1] See Appendix 8-1 for derivation and assumptions.

The data are also classified according to physiographic zone, landuse type, and soil horizon. The mean values of each subgroup for both TOTALP and TOTALQ are shown in Tables 8-1a & 8-1b. It can be readily seen that these two tables show essentially the same pattern. Because of the exclusion of splashed particles that are assumed to have moved upslope, TOTALP tends to show smaller values in many subgroups.

Generally, the decrease in soil erodibility from the plains to the mountains and to the foothills are demonstrated. Superimposed on this regional trend are the effects of landuse practices and vegetation cover. Cultivated soils in the prairies are extemely erodible. The fact the B horizon soils under forest are more erodible than those under grass is also shown. Unprotected soils tend to be very variable in their erodibility, ranging from high relative erodibility for freshly exposed sites to extremely low erodibility where most of the top soil has already been eroded. For grassland soils, B horizon samples are more erodible in the prairies.

8.2.2 Field Measurements

It is hard to generalize from the field data because of the lower degree of experimental control and the relatively small amount of data available. During the field season of 1974, prairie sites were found to show the highest rate of erosion (Table 7-3). However, this is at least partly explained by a longer period of record and generally poorer cover in the sampled sites.[2] To remove the effects of rainfall (Rf) and cover (K), Equation 7.10.3 is used. An erodibility index (SEI) is computed, using 101.6 mm of rain and 100 percent bare ground as reference :

$$SEI = SL \times (101.6/Rf)^{0.22} \times (100/K)^{0.11} \quad (8.3)$$

where SL is measured soil loss in g/m².

Since slope was not found to be related to soil loss, it is thought that its effect is minimal on the computed index. It is also understood that effects of variations in rainfall intensity and antecedent soil moisture content were not removed.

For convenience of presentation, these indices were grouped according to site and the mean value for each site is plotted against their respective elevations (Fig. 8-1). Since only 1974 data were used and no adequate rainfall data were available for the two forested plots, only 14 points were plotted in this figure. Also included in the same figure are the mean TOTALP and mean TOTALQ for each sampled unit against their respective mean elevations.

Except for #W5, #P5, and the two mountain plots, field results fit in remarkably well with the laboratory data. The departure of #W5 and #P5 from the regional pattern is probably because not all the selected sites can be representative of the units studied. It seems reasonable, therefore, to interpret this figure (Fig. 8-1) as reflecting the concurrence of laboratory and field data on the regional pattern of variations in soil erodibility in the studied areas. Departures from the regional trend are basically the result of local variations in environmental factors, largely the type of parent material.

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[2] There is no indication that during this season prairie sites received more rainfall.

Comparable data in the same region are only available in two studies. Bryan (1974) found a general increase in the erodibility of Albertan soils from the west to the east, roughly corresponding to increasing aridity in the region. Kemper & Koch (1965) studied aggregation characteristics of some 500 soils in western United States and Canada and observed the best aggregated soil in regions with 20 inches (500 mm) annual precipitation. The decrease in aggregate stability beyond 500 mm precipitation, however, is thought to be related to temperature effects. Otherwise, as precipitation increases, soil aggregation should improve in conjunction with organic matter content.

That foothills soils are generally less erodible than prairie soils can be explained by the cooler and moister climate which generally favours rapid vegetation growth in the summer but slower rates of residue decay and therefore greater amount of humus accumulation. This is generally shown by the better aggregation and higher organic content of the foothills soils. In the upper foothills and mountain areas, increasing humidity favours higher rates of eluviation. Mini-Pozolic B horizons were observed in the upper Three Point Creek and Cataract Creek basins. Podzolic profiles are also reported in the Kananaskis valley (Crossley 1951, Karkanis 1973). These soils tend to have less organic content (other than L-F-H layers) and clay content in their surface horizons and therefore poorer aggregation. No systematic classification of soil types[3] in the studied areas have been attempted but it suffices to refer to soils observed in Northfork East Section which shows that the highly degraded soils at site #14 and #16 have higher erodibilities than others which are less degraded within the same area.

Another related factor is the more extensive distribution of residual soils (despite the presence of thin tills) from the upper foothills to the mountains. Often developed on Mesozoic sandstone, these soils tend to be coarse textured even if profile development is at an advanced stage. This coarse texture also contributes to the higher erodibility of upper foothills and mountain soils. Because these soils usually have a massive structure their sandy nature partly explains their higher erodibility.

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[3] Such as the System for Soil Classification in Canada

8.3 Tests of Laboratory Model

8.3.1 Background

The testing of the prediction model developed from laboratory data against observed field data requires a consideration of rainfall intensity. Because laboratory data were obtained under constant rainfall intensity, an assumption to this effect has to be made for the field data. Thus observed soil loss (OSL) data in the field are corrected for rainfall amount by referring to a constant amount, 101.6 mm, the amount used in the laboratory. Corrected soil loss (CSL) is computed by the formula :

$$CSL = OSL \times (101.6/Rf) \quad (8.4)$$

Since OSL was not found to be related to slope, it was speculated that this may be the result of the dominance of rainsplash erosion which causes an undercatch of eroded particles at higher slopes (Section 7.3). Accordingly, a correction for this undercatch was attempted. Since the plots are of uniform length, the height of the uppermost point of the plot varies with the sine of the slope angle. It is therefore thought that if a correction is to be made, it should be some mathematical function of the sine function, and the possible forms of this function may range from $\sin\theta$ to $2 \times \sin^2\theta$.

According to this reasoning, two additional corrected

OSL's (CSL1, CSL2) were computed by the formulae :

$$CSL1 = (\mathrm{Log}(CSL) + 1) \times (1 + \sin\theta) \quad (8.5)$$

and $$CSL2 = (\mathrm{Log}(CSL) + 1) \times (1 + 2\sin\theta^2) \quad (8.6)$$

The simplified laboratory model involving four 'independent' variables : cover density, slope, aggregate size, and organic content, is used in this test because on theoretical grounds it should be more applicable to the field situation and in practice a simpler model has a wider application if the test result is positive. An alternative model incorporating two more variables : clay fraction and coarse sand content is utilized (Appendix 8-2). These are referred to as Model A and Model B respectively. In actual testing, it is possible to use field data at two different temporal scales, the period level and the season level. Only 1974 data were used for the period level test because the 1973 data tend to have too long a measurement period to be comparable to the former. For the season level test, data for the 1973 and 1974 seasons were used.

8.3.2 Period Data

All the 63 valid plot-period cases are considered. Three OSL variables : CSL, CSL1, CSL2 are computed according to Equations 8.4 - 8.6. Predicted soil loss (PSL) variables according to Model A (Equation 6.7) and Model B (Appendix 8-2) are also computed. Correlation results of the OSL's vs PSL's are presented in Table 8-2. The 'r' values range from

0.5 to 0.6 and all of them are significant at the 0.1% level. The use of corrections for splash loss only give slightly better results in Model A but poorer results in Model B. Use of Model B which incorporates more variables shows less significant results and therefore the Model is inferior to Model A in predicting observed soil loss.

Examination of the scattergrams (Fig. 8-2) suggests a curvilinear fit for the log-log plots. An attempt was therefore made to use polynomial equations to fit the data. It was found that third order polynomial curves fit the data better than the linear functions.* Correlation coefficents generally increase to 0.6 - 0.65.

8.3.3 Season Data

Twenty-nine sets of season data for 17 plots and for the summer seasons 1973 and 1974 are used in this analysis. The procedures are exactly as for the period data. Again Model A and Model B for predicted soil loss and two different slope corrections for observed soil loss were used. Correlation results (Table 8-2) are generally better than the case for plot-period data; 'r' values range from 0.65 to 0.75 and are significant at the 0.1% level. Slope corrections do not improve the fit and Model A, using fewer variables, seems to give slightly better results than Model

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* Strictly speaking, the original power function relation is also a non-linear function.

B. Fig. 8-3 shows the difference between the fit for the two Models.

8.3.4 Interpretations

The significance of the goodness of fit of predicted and observed soil loss data in both the period and season sets lends credence to the laboratory simulation model developed in Section 6.6. Other evidence including the comparability of the underlying controls for both simulated and field soil loss, and the general concurrence of laboratory and field estimation of soil erodibility, also suggest a positive result for this test of the laboratory model.

However, the range for application of the model should be emphasized. Whilst dominant erosion processes in both field plots and laboratory 'sample pans' may be similar, field erosion processes outside the plots can be entirely different. Under these conditions, slope length is unrestricted and if runoff is generated on these slopes, much more sediment can be transported and erosion rates should then be considerably higher. The effect of slope length has been reviewed (Section 1.6.4).

Another limitation of the model is the assumption of constant rainfall amount and intensity. Whilst soil erodibility is measured under constant rainfall, actual rainfall erosivity has a very large spatial and temporal variability. This latter factor must be considered in estimating regional patterns of erosion potential.

8.4 Regional Pattern of Erosion Potential

8.4.1 Soil Erodibility

Since the laboratory model was substantiated by testing against field data, soil erodibility data (Section 5.3) are generalized to cover all mapped units. Although the procedure adopted incorporates a certain amount of subjective element, it is thought that the pattern developed out of this procedure is sufficiently accurate to describe the regional pattern of soil erodibility in the study area.

For this procedure, TOTALP was chosen to be the data base. In view of its relationship with TOTALQ it probably makes very little difference in the final pattern developed if either one index is chosen. For ease in generalizing data, a soil erodibility index (SEI) was computed by dividing each TOTALP by the lowest value of TOTALP observed (Appendix 8-2). The resultant series of SEI ranges from 1 to over 200. These indices are then grouped at intervals of 25 (an arbitrary interval), giving a total of 9 grades.

Then, based on field observations of soil characteristics and their relationships to slope, cover, and parent material, each 'site' is assigned an erodibility value (1 to 9). The area of each 'site' is then estimated by a simple weighing method.[5]

Mean SEI of the entire unit is then computed by the formula :

$$\text{Mean SEI} = \sum_{i=1}^{n} [\text{SEI}_i \times (A_i / \sum_{i=1}^{n} A_i)] \quad (8.7)$$

where SEI_i is erodibility index for each site, A_i is area of each site, and n is the total number of sites in each unit. The SEI values were taken to be the equivalent class mid-mark of each group. The result of this computation is presented in Table 8-3 and in a graph plotting mean soil erodibility for each unit against elevation (Fig. 8-4).

The plot appears to be a refinement of Fig. 8-3 and shows clearly the regional pattern of soil erodibility. Erodibility decreases with increasing elevation from the plains. The lowest value occurs at around 1 350 m (4,500 ft), then rises to a peak at about 1 900 m (6,200 ft). It gradually falls again beyond 1 900 m. This pattern appears to be related to regional topographic and precipitation characteristics. The minimum is located at the lower foothills and the secondary peak is found at about the top of the upper foothills (eastern slope of Front Range).

However, this figure should be interpreted with considerable caution because it is only based on 17 rather subjectively selected units. Also there is a considerable amount of subjective element involved in generalizing the data. Furthermore, this generalization neglects latitudinal variations which therefore limit its applicability to a small zone in Southern Alberta.

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[5] The base maps are reproduced on ozalid paper. Each unit is cut up into 'sites' and the weight of each 'site' is determined in a Mettler analytical balance which is accurate to ± 1 mg. Unit area weight of the paper is then calibrated by weighing sheets of known area. The accuracy of this method is found to be within ± 1 percent.

8.4.2 Erosion Potential

For estimation of erosion potential, cover, slope, and rainfall factors have to be considered. This section is only concerned with slope and cover. Rainfall will be treated at a more general scale in Section 8.5.

Mean cover and slope for each unit were computed using the data from field mapping and by relating each slope or cover class to equivalent values. For slope, the equivalent values of A, AB, and B slopes are 30°, 10°, and 3° respectively. For cover density, the equivalent for cover class 1, 2, 3, and 4 are 2.5, 11, 45, and 100 percent respectively.[6] The formulae :

$$\text{Mean Slope} = \sum_{i=1}^{n} \left(\theta_i \times A_i / \sum_{i=1}^{n} A_i\right) \qquad (8.8)$$

$$\text{and Mean Cover Density} = \sum_{i=1}^{n} \left(K_i \times A_i / \sum_{i=1}^{n} A_i\right) \qquad (8.9)$$

where θ_i and K_i are slope and cover density of each site, A and n as defined in Equation 8.7 are used. The results are presented in Table 8-3.

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[6] The equivalent cover values are geometric mean values of cover classes 0 to 6 percent, 6 to 20 percent, 20 to 99 percent, and 100 percent respectively.

With this information, it becomes possible to compute soil erosion potential (SEP) of each unit under identical rainfall conditions. The formula used is derived in Section 6.6.5 :

$$SEP = SE \times (K/100)^{0.925} \times (\sin\theta\cos\theta/\sin 20^\circ\cos 20^\circ)^{0.33} \tag{8.10}$$

The results are shown in Table 8-3 and plotted in Fig. 8-5. This figure shows a similar regional pattern found for SEI except for the fact that because the prairie units are all cultivated areas, the differences between prairie and foothills units becomes much more pronounced.

Apart from the limitation of the SEI distribution pattern described in Section 8.4.1, this representation of soil erosion potential is inaccurate because slope and cover data are very generalized. It neglects the effect of the presence of forest litter cover (because well-covered forest and grass sites are all given class 1 cover density). Also use of an 'A' slope to cover all slopes above 16° tends to under-estimate slope steepness in the upper foothills and mountain areas. These are considered in a more general application of the data in the next section.

8.5 Relationship of Erosion Potential to Sediment Yield

Since not enough is known about the distribution of soil erodibility characteristics outside the sampled units, further generalization of data is impracticable. Instead, the data are considered to represent 'an average unit' of each of the basins studied. The average slope and cover characteristics of each basin, together with regional rainfall characteristics, could then be utilized to compute basin gross erosion rates. The relationship of gross erosion rate to known sediment yield data is then speculated.

8.5.1 Basin Gross Erosion Rates

Because of the small areas studied, 'average' soil erodibility of each basin (Table 8-4) should be considered only an indication of order of magnitude. Average slope of each basin is taken from Table 2-1. Estimated data on landuse types in each basin are available (Table 2-2). To convert these estimates to cover density figures, forest/woodland is considered to have 2 percent bare ground, grass 5 percent, and cultivated land 50 percent. Small areas of barren rock surfaces are also assigned 2 percent density.

For the present purpose, it is necessary to know the frequency of occurrence of different rainfall intensity classes. Unfortunately such data are not available. To approximate spatial variations in rainfall erosivity, mean annual maximum 24-hr rainfall intensity (Pollock & Gaye 1973) and mean annual rainfall of representative stations in the area were used. Erosivity was found to be a function of the product term of intensity and kinetic energy (Wischmeier & Smith 1958) but the relation of rainfall intensity and rainfall energy in this part of the province is unknown. To approximate this effect, the square of maximum rainfall intensity is used. Thus in the actual computation, rainfall erosivity is assumed to be proportional to :

$$I^2 \times Rf$$

where I is mean annual maximum 24-hr rainfall intensity and Rf is mean annual rainfall. These data are shown in Table 8-4.

For the computation of gross erosion rate, erosion is assumed to vary directly with rainfall erosivity and cover. The slope function of $\sin\theta\cos\theta^{0.33}$ is probably not applicable to field situations where slope length is much longer. On the other hand, the tangent slope function of 1.4 (Zingg 1940) appears unrealistic since for high cover densities as found in the foothills and mountains, the effect of slope angle is much reduced (Meeuwig 1971). A tentative exponent of 1.0 for slope angle (in degrees) is chosen. Thus

$$GER = SE \times \theta^{1.0} \times K^{1.0} \times (RE)^{1.0} \quad (8.11)$$

where GER is gross erosion rate, SE soil erodibility, and RE rainfall erosivity. The final computation results are shown in Table 8-4. West Arrowwood Creek is found to have the highest rate, followed by Three Point Creek.

CHAPTER NINE

CONCLUSIONS

In relation to erosional processes, the various sediment source areas may be considered either components of sheet or channel type erosion. Sediment source areas, on the other hand, refer to those areas where conditions of cover, slope, soil erodibility, and rainfall erosivity are conducive to sediment production. Sediment transport capacities are directly related to discharge conditions in major drainage channels.

All available sediment yield data for the study area are shown in Table 9-1. Since the mountain and foothills basins should have reasonably high sediment delivery ratios, computed Gross Erosion Rate should be somewhat related to sediment yield. Examination of the data shows that this is the case for Cataract Creek, Pekisko Creek, and Stimson Creek but Three Point Creek has a much higher sediment yield. On several occasions, turbid water carrying a relatively high sediment load was observed up the Three Point Creek, above the Ranger Station. Air photo studies reveal that upstream at Volcano Creek there is a stretch of extensive cutbanks of about 10 km long, apparently developed on very erodible material (Laycock 1957b). Its total area is about 2.5 km², and its contribution could be up to

50 000 m-tons per year, a rate extrapolated from similarly erodible material in the Swan Hills (Wyldman & Poliquin 1973). Since the mean annual yield of the Creek at Millarville is about 63 000 m-tons (McPherson 1975), it is possible that the greater part of the excessive yield of the Creek is contributed by this stretch.

It is not known how accurate is the estimated yield of 21 000 to 34 000 m-tons at West Arrowwood Creek. Published data (McPherson 1975) cover only basins in the Cypress Hills area where arable landuse is much less extensive than in the prairie watersheds above Bassano Dam.

Certain conclusions concerning sediment sources have been drawn, though clearly additional information on soil erodibility and precipitation erosivity would be highly advantageous. Nevertheless, this study provides several indicators regarding sediment source areas in the region.

The calculated rate of sediment yield of 1.3 x 10^6 m-tons per year at the Bassano Dam, or 68 m-tons/km^2 (Hollingshead, Yaremko, & Neill 1973) as a regional erosion rate, is not excessive when compared to rates reported by Langbein & Schumm (1958), Gottschalk (1964), Wilson (1973), Stichling (1973), and Slaymaker & McPherson (1973). However, because of dam constructions upstream, this average figure over a period of 60 years probably does not reflect present rates of sedimentation.

To evaluate sources of sediment production, regional sediment yield is estimated on the basis of analysis results and published data (Table 9-2). Estimated yield from the mountains and foothills areas is about 48 x 10^3 to 146 x 10^3 m-tons. This is comparable to the yields measured at Highwood near the mouth for 1972 and 1973 (Table 8-5).

An attempt [illegible]educe present rates of sedimentation at the Bassano Dam (Table 9-3) shows that the estimated annual rate is only 350 x 10^3 to 700 x 10^3 m-tons, a rate much lower than the long-term average of 1.3 x 10^6 m-tons derived from sediment surveys.

The key to the explanation of this discrepancy lies in the accuracy of estimation of the contributions of prairie watersheds. From the point of view of long term sediment contribution, what is eroded must eventually be removed, although the mean residence time of eroded particles in river channels may vary (Wilson 1973). Since prairie soils are highly erodible and field observations do not indicate significant amounts of channel alluviation except in ditches, the rates of yield in the prairie watersheds may be higher than what is estimated. It is also possible that wind erosion is responsible for a significant amount of within-basin transfer of eroded soil.

Alternatively, because of upstream sediment storage and decreasing trap efficiency due to infilling, the present sedimentation rates may be lower than the long term average rate.

In the light of the above discussions, three source areas appear to be significant contributors to sedimentation at the Bassano Dam :

(a) excessively erodible glacial/alluvial deposits and bedrock along the major drainage channels such as along Volcano Creek in the Three Point Creek Basin and along the upper Sheep River north of Gibraltar Mountain;

(b) steeply sloping coulee sides, ditches, and cultivated land on moderate slopes in the prairies; and

(c) cultivated and poorly grazed areas in the foothills where rainfall erosivity and sediment delivery rates are higher than in the prairies.

In considering these source areas, however, it should be noted that rainfall erosion is only one of the processes responsible for sediment production. Fluvial and eolian processes are probably of considerable importance but were not considered. This study has concentrated on rainfall erosion effects and has shown that these may play a significant role both locally and regionally.

TABLE 1-1

SAMPLED UNITS & PLOT SITES BY DRAINAGE BASINS

Basin	No. of Units	No. of Plots
Cataract Creek	3	6
Three Point Creek	5	8
Pekisko Creek	1	2
Stinson Creek	3	6
West Arrowwood Creek	5	8
Total	17	30

TABLE 3-1

MORPHOMETRIC PROPERTIES OF SELECTED BASINS

Basin	Drainage Basin Area (km^2)	Effective Drainage Area (km^2)	Mean Elevation (m)	Mean Relief (m)	Mean Ground Slope (°)	Channel Gradient (m/km)
Cataract Creek	165	165	2 008	257	21.5	16.1
Three Point Creek	502	499	2 471	80	14.9	8.5
Pekisko Creek	228	192	1 490	92	10.7	6.7
Stimson Creek	249	239	1 379	31	6.8	2.8
West Arrowwood Creek	738	685	1 011	16	1.3	1.0

Source: Canada Topographical Map (1:50 000) Series Nos. 82-J, 82-O, 82-P.

TABLE 3-2

ESTIMATED PERCENTAGES OF LAND USE TYPES IN THE SELECTED BASINS

Basin	Within Forest Reserve			Outside Forest Reserve		
	Forest	Barren	Grassland	Forest/Woodland	Grassland	Cultivated Land
Cataract Creek	90.7	8.1	1.2	---	---	---
Three Point Creek	55.1	---	---	25.0	8.5	11.4
Pekisko Creek	36.6	---	---	20.5	35.7	7.1
Stimson Creek	17.1	---	---	25.2	50.9	6.8
West Arrowwood Creek	---	---	---	---	6.3	93.7

Source: A.R.D.A. Land Use Map Series; Composite Forest Series, Dept. of Land & Forest, Alberta; method used disregard any landuse type occupying <0.25 mi^2 (0.65 km^2) area.

TABLE 3-3

MEAN MONTHLY TEMPERATURE OF NINE SELECTED STATIONS

Station	J	F	M	A	M	J	J	A	S	O	N	D
Lake Louise	-14.6	-9.0	-6.4	0.2	5.9	9.6	12.4	11.4	7.3	1.8	-7.1	-12.4
Banff	-11.2	-6.8	-3.8	2.3	7.5	11.2	14.5	13.4	9.1	4.2	-3.8	-08.7
Kananaskis	-09.7	-6.1	-4.2	1.8	7.1	10.7	14.1	14.1	9.2	5.0	-2.3	-06.1
Kananaskis LO	---	---	---	---	---	7.8	12.1	10.8	6.6	0.8	---	---
Highwood RS	-09.9	-6.9	-5.0	1.8	6.4	9.9	13.2	12.0	8.3	4.2	-2.2	-06.2
Pekisko	-10.1	-7.0	-5.4	1.4	6.6	10.2	13.3	12.3	8.4	4.3	-2.8	-06.9
Turner Valley	-12.5	-7.2	-5.8	1.4	7.7	11.4	14.4	13.3	8.9	4.4	-2.8	-07.8
Gleichen	-13.1	-9.1	-4.4	4.4	10.6	14.4	17.6	16.3	11.2	5.8	-3.4	-09.3
Vulcan	-11.4	-7.8	-4.3	4.4	10.2	14.1	17.8	16.6	11.6	6.6	-2.1	-07.3

Source: Atmospheric Environment Service, Environment Canada (1973); Degrees in Centigrade

TABLE 3-4

PERCENTAGE MONTHLY MAXIMUM RAINFALL INTENSITY FREQUENCIES OF EIGHT ALBERTA STATIONS, MAY TO SEPTEMBER INCLUSIVE

Station (Period of Record) (Elevation)	Monthly Maximum Fall in Periods (minute)	Number of Months (f)	'f' with Intensity 12.7 mm/hr	Percent of Total	Maximum Intensity Recorded (mm/hr)
Calgary 1961 - 74 1 079 m	15	65	28	43	91
	30	65	18	28	61
	60	65	6	9	36
Lethbridge 1961 - 74 920 m	15	67	35	52	105
	30	67	20	30	66
	60	67	8	12	35
Vauxhall 1961 - 74 779 m	15	67	22	33	78
	30	67	14	21	52
	60	67	6	9	29
Kananaskis 1966 - 74 1 390 m	15	21	10	48	59
	30	21	6	29	39
	60	21	1	5	19
Highwood Summit 1964 - 74 2 210 m	30	25	3	12	20
	60	44	1	2	13
Streeter #7 1965 - 72 1 402 m	15	21	13	62	63
	30	21	11	52	31
Marmot Con 4 1962 - 73 1 718 m	15	22	9	41	49
	30	22	4	18	43
	60	22	2	9	25
Marmot Con 5 1962 - 73 1 753 m	15	27	8	30	41
	30	27	4	15	30
	60	27	2	7	21

Data Source : Monthly Records, Meteorological observations in Canada, Atmospheric Environment Service, Canada Department of Environment, Toronto, 1961 - 73; Compilation of Hydrometeorological Record, Marmot Creek Basin, v.1 to 9, data assembled by Water Survey of Canada for internal circulation; Compilation of Hydrometeorological Record, Streeter Creek Basin, v.1 to 9, data assembled by Water Survey of Canada for internal circulation; Highwood Summit data made available by Mr. D. Storr, Atmospheric Environment Service, Alberta Environment, Calgary office.

TABLE 3-5

NORMAL POTENTIAL EVAPOTRANSPIRATION, SURPLUS, & DEFICIT OF EIGHT SELECTED STATIONS

Station	PPT	PE	SUR	DEF
Lake Louise	768	376	417	25
Banff	477	465	98	87
Kananaskis	647	481	195	28
Calgary A	437	520	7	91
Pekisko	687	436	270	19
Turner Valley	584	466	142	25
Gleichen	410	569	3	162
Lethbridge A	436	574	22	161

PPT = precipitation; PE = potential evapotranspiration; SUR = water surplus; DEF = water deficit; all measurements in mm.

TABLE 4-1

DISTRIBUTION OF COLLECTED SAMPLES BY UNIT

Basin	Unit		No. of Samples
Cataract Creek	Cataract Central	(CC)	13
	Cataract North	(CN)	9
	Cataract South	(CS)	15
Peksiko & Stimson Creek	Blades	(PB)	18
	Cartwright	(PC)	30
	Spruce Ranching	(PR)	14
	Smith	(PS)	16
Three Point Creek	Charmes	(TC)	21
	Northfork East	(TE)	16
	McMurtry	(TM)	13
	Northfork West	(TN)	11
	Ware Creek Southwest	(TW)	19
West Arrowwood Creek	Andrews	(WA)	4
	Campbell	(WC)	9
	Merkel	(WM)	11
	Steiner	(WS)	9
	Weber	(WW)	5

TABLE 4-2

BASIC DATA FOR CALIBRATION OF RAINFALL SIMULATOR

Run	Total Rainfall (mm)	Intensity (mm/hr)
1	16.8	100.8
2	16.5	99.1
3	16.9	101.1
4	17.0	102.9
5	17.9	107.2
6	16.7	100.1
7	16.6	99.6
8	16.6	98.0
9	16.6	99.8
10	17.7	106.2
mean	16.9	101.5
s.d	0.5	2.9

Runs of 10 min. duration.

TABLE 5-1a

TESTED SAMPLES BY LANDUSE TYPES AND SOIL HORIZON

Section	Landuse Types				Soil Horizon				Total
	1	2	3	4	A	Ap	B	C	
CC	4	0	5	0	0	0	5	4	9
CN	1	1	4	0	0	0	5	1	6
CS	1	3	2	0	1	0	4	1	6
PB	0	16	0	0	15	0	1	0	16
PC	3	18	1	0	17	0	4	1	22
PR	1	7	0	0	5	0	2	1	8
PS	0	7	0	0	5	0	2	0	7
TC	2	8	0	0	8	0	1	1	10
TE	0	4	4	0	6	0	2	0	8
TM	0	6	0	0	4	0	2	0	6
TN	0	3	1	0	1	0	3	0	4
TW	1	4	5	0	4	0	5	1	10
WA	0	1	0	3	1	3	0	0	4
WC	2	2	0	5	1	5	3	0	9
WM	4	3	0	5	2	5	3	2	12
WS	2	2	0	5	2	5	1	1	9
WW	0	1	0	4	1	4	0	0	5
Total	21	86	22	22	73	22	43	13	151

Landuse Types : 1 = bare; 2 = grass; 3 = forest;
4 = cultivated.

TABLE 5-1b

TESTED SAMPLES BY SLOPE AND COVER DENSITY

Test Slope	3°				10°				30°				
Cover % Section	5	15	45	100	5	15	45	100	5	15	45	100	Total
CC	0	0	0	0	0	0	0	0	0	1	2	6	9
CN	0	0	0	1	1	0	0	0	0	0	2	2	6
CS	0	0	0	2	0	0	0	2	0	1	0	1	6
PB	1	1	0	0	6	3	0	0	2	1	2	0	16
PC	1	1	0	1	4	1	0	1	2	7	3	1	22
PR	0	1	0	0	2	2	0	0	2	1	0	0	8
PS	1	0	0	0	2	0	0	0	2	2	0	0	7
TC	1	0	1	1	2	1	0	0	1	2	1	0	10
TE	0	0	0	1	0	0	0	3	0	1	1	2	8
TM	1	0	0	0	3	1	0	0	0	1	0	0	6
TN	0	0	0	0	0	0	0	2	2	0	0	0	4
TW	1	0	0	1	1	1	0	2	0	1	0	3	10
WA	0	0	2	1	0	0	0	0	0	1	0	0	4
WC	0	0	2	1	0	0	3	0	1	0	2	2	9
WM	1	1	3	1	1	0	1	0	0	0	4	4	12
WS	1	0	2	2	0	0	0	0	1	1	1	1	9
WW	1	0	2	1	0	0	0	0	1	0	0	0	5
Total	9	4	12	13	22	9	4	10	14	20	12	22	151

TABLE 5-2

SOIL LOSS VARIABILITY TEST DATA

Run	TOTALD (g/m^2)	TOTALW (g/m^2)	TOTALT (g/m^2)	Remarks
R1	509	573	1082	
R2	477	602	1079	
R3	532	637	1169	
R4	528	623	1151	
mean	562	609	1120	
s.d.			46.2	
R5	491	574	1065	
R6	364	444	808	c
R7	624	754	1378	f
R8	352	447	799	c
R9	429	568	997	
mean	452	557	1009	
s.d.			260	

c : coarse particles on surface
f : finer particles on surface

TABLE 5-3a

NOMENCLATURE FOR SOIL LOSS VARIABLES

Run	Variable	ABBREVIATION	SYMBOL
Dry Run Soil Loss	Wash loss	WAASHD	Wd
	Splash loss	SPASHD	Sd
	Total loss	TOTALD	Td
Wet Run Soil Loss	Wash loss	WAASHW	Ww
	Splash loss	SPASHW	Sw
	Total loss	TOTALW	Tw
Dry + Wet Run Soil loss	Wash loss	WAASHT	Wt
	Splash loss	SPASHT	St
	Total loss	TOTALT	Tt
Wet Run with Cover Density Simulation	Wash loss	WAASHV	Wv
	Splash loss	SPASHV	Sv
	Total loss	TOTALV	Tv

TABLE 5-3b

NOMENCLATURE FOR OTHER VARIABLES

Group	Variable	Abbreviation	Symbol
Aggregation	%-wt WSA 2.83 mm	PWSAG3	-
	%-wt WSA 2 mm	PWSAG2	-
	%-wt WSA 1 mm	PWSAG1	-
	%-wt WSA 0.5 mm	PWSAGH, AGG	G
	Mean Weight Diameter	MWD	-
	Geometric Mean Diameter	GMD	-
Texture	Clay Fraction	CLAY	Cy
	Silt Fraction	SILT	Si
	Sand Fraction	SAND	Sn
	Coarse Sand, 0.5 - 4 mm	CRSD	Cs
Runoff	Dry Run	RUNOFD	Rd
	Wet Run	RUNOFW	Rw
	Dry + Wet Run	RUNOFT	Rt
Others	Organic Carbon Content	OCC	C
	Bulk Density	BKDY	BD
	Cover Density	COVER	K
	Slope Angle	SLOPE	θ

TABLE 5-4

DESCRIPTIVE STATISTICS FOR UNTRANSFORMED SOIL LOSS AND RUNOFF VARIABLES

Variable	$\bar{x}$	s.d.	min	max	sk	n
WAASHD	47.8	98.7	0.1	878.7	5.4	148
SPASHD	174.9	196.3	6.2	860.1	1.8	148
TOTALD	222.7	240.3	6.6	1293.9	1.6	148
WAASHW	87.8	133.7	0.1	814.1	2.6	148
SPASHW	216.4	173.0	5.7	860.1	1.2	148
TOTALW	304.2	21.2	6.0	1204.4	1.1	148
WAASHT	135.6	225.0	0.2	1692.8	3.6	148
SPASHT	391.3	362.5	11.9	1557.5	1.5	148
TOTALT	526.9	487.9	12.6	2498.0	1.3	148
WAASHV	13.3	22.0	0.03	107.8	2.8	97
SPASHV	61.7	85.8	2.7	339.5	1.9	97
TOTALV	75.0	101.5	3.0	357.9	1.7	97
RUNOFD	1.864	3.549	0.0	23.83	3.4	151
RUNOFW	3.705	5.842	0.0	30.47	2.0	151

$\bar{x}$ = mean; s.d. = standard deviation; min = minimum; max = maximum; sk = skewness; n = sample size; soil variables in g/m^2; runoff variables in mm.

TABLE 5-5

REGRESSION EQUATIONS FOR DRY RUN VS WET RUN SOIL LOSS VARIABLES FOR THREE DIFFERENT TEST SLOPES

Test Slope	y	x	a	b	R^2	n
3°	WAASHD	WAASHW	0.51	0.91	0.94	38
	SPASHD	SPASHW	0.18	1.26	0.94	38
	TOTALD	TOTALW	0.22	1.21	0.95	38
10°	WAASHD	WAASHW	0.69	0.74	0.75	45
	SPASHD	SPASHW	0.60	0.97	0.93	45
	TOTALD	TOTALW	0.65	0.95	0.94	45
30°	WAASHD	WAASHW	0.71	0.95	0.87	65
	SPASHD	SPASHW	0.53	1.05	0.85	65
	TOTALD	TOTALW	0.49	1.05	0.91	65

For regression model $y = ax^b$; R^2 = coefficient of determination; n = sample size.

TABLE 5-6

COEFFICIENTS OF CORRELATION AMONG SIX AGGREGATION INDICES

	PWSAG3	PWSAG2	PWSAG1	PWSAGH	MWD	GMD
PWSAG3	1.00	0.92	0.88	0.83	0.89	0.88
PWSAG2		1.00	0.96	0.88	0.95	0.93
PWSAG1			1.00	0.97	0.98	0.99
PWSAGH				1.00	0.96	0.99
MWD					1.00	0.98
GMD						1.00

sample size = 151; significance level : for $p \leq 0.1\%$, $r \geq 0.29$.

TABLE 5-7

COEFFICIENTS OF CORRELATION (r) : SELECTED SOIL LOSS VARIABLES VS SIX INDICES OF AGGREGATION FOR THREE TEST SLOPES

	PWSAG3	PWSAG2	PWSAG1	PWSAGH	MWD	GMD
TOTALD	-0.66	-0.71	-0.75	-0.76	-0.73	-0.75
TOTALW	-0.64	-0.69	-0.71	-0.71	-0.68	-0.71
TOTALT	-0.65	-0.71	-0.74	-0.74	-0.71	-0.73
(a) SLOPE = 3°, n = 38.						
TOTALD	-0.70	-0.73	-0.75	-0.74	-0.75	-0.75
TOTALW	-0.66	-0.71	-0.72	-0.70	-0.71	-0.72
TOTALT	-0.67	-0.73	-0.73	-0.71	-0.73	-0.75
(b) SLOPE = 10°, n = 45.						
TOTALD	-0.30	-0.42	-0.55	-0.57	-0.52	-0.55
TOTALW	-0.36	-0.49	-0.58	-0.58	-0.55	-0.60
TOTALT	-0.34	-0.47	-0.57	-0.58	-0.54	-0.58
(c) SLOPE = 30°, n = 65.						

All 'r' values are significant at the 5% level

TABLE 5-8

DESCRIPTIVE STATISTICS OF PERCENTAGE WEIGHT WATER STABLE AGGREGATES GREATER THAN 0.5 mm CLASSIFIED BY PHYSIOGRAPHICAL ZONE, LANDUSE TYPES, AND SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	$\bar{x}$	---	37.2	---	---	38.3	49.3	22.4	31.3	15.4
	s.d.	---	---	---	---	15.8	9.1	---	11.3	11.3
	n	---	1	---	---	61	4	1	6	22
B	$\bar{x}$	---	52.7	37.0	43.2	50.0	50.4	24.1	36.8	---
	s.d.	---	4.0	18.2	37.6	16.7	24.7	6.2	7.9	---
	n	---	3	11	3	12	7	5	2	---
C	$\bar{x}$	30.4	---	---	29.4	---	27.0	7.7	---	---
	s.d.	9.9	---	---	21.9	---	2.8	---	---	---
	n	6	---	---	4	---	2	1	---	---

Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated; $\bar{x}$ = sample mean; s.d. = standard deviation; n = sample size.

TABLE 5-9

DESCRIPTIVE STATISTICS OF PERCENTAGE ORGANIC CARBON CLASSIFIED BY ZONE, LANDUSE, & SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	$\bar{x}$	---	12.32	---	---	8.58	7.63	4.27	5.83	3.86
	s	---	---	---	---	2.94	2.16	---	2.57	1.31
	n	---	1	---	---	61	4	1	6	22
B	$\bar{x}$	---	2.75	2.11	4.28	4.39	1.63	1.29	3.58	---
	s	---	0.20	1.14	1.07	1.13	1.01	0.23	0.24	---
	n	---	3	11	3	12	7	5	2	---
C	$\bar{x}$	0.823	---	---	1.43	---	---	0.49	2.02	---
	s	0.190	---	---	0.27	---	---	0.14	---	---
	n	6	---	---	4	---	---	2	1	---

Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated; $\bar{x}$ = sample mean; s = standard deviation; n = sample size.

TABLE 5-10

COEFFICIENTS OF CORRELATION : SOIL PROPERTY VARIABLES VS SELECTED SOIL LOSS VARIABLES

	AGG	SAND	CLAY	OCC	CRSD
	Grassland, A Horizon slope = 10°, n = 28				
WAASHD	-0.68***	0.17	0.00	0.08	0.20
SPASHD	-0.82***	0.27	-0.23	0.01	0.26
TOTALD	-0.82***	0.27	-0.21	0.02	0.26
TUNOFD	-0.27	0.08	0.08	0.21	0.05
WAASHW	-0.59***	0.02	0.05	-0.24	0.17
SPASHW	-0.76***	0.23	-0.19	-0.10	0.26
TOTALW	-0.75***	0.21	-0.17	-0.11	0.25
RUNOFW	-0.13	0.13	-0.12	0.12	-0.07
	Grassland, A Horizon slope = 30°, n = 22				
WAASHD	-0.48*	0.38	-0.48*	-0.03	0.65***
SPASHD	-0.48*	0.37	-0.39	-0.10	0.45*
TOTALD	-0.48*	0.38	-0.42	-0.08	0.53*
RUNOFD	0.04	-0.54**	0.39	-0.08	-0.18
WAASHW	-0.44*	0.31	-0.41	-0.03	0.63*
SPASHW	-0.46*	0.27	-0.26	0.02	0.48*
TOTALW	-0.45*	0.28	-0.29	0.01	0.53*
RUNOFW	0.05	-0.41	0.21	-0.12	0.09
	Forest, B Horizon slope = 30°, n = 8				
WAASHD	-0.75*	0.46	-0.25	-0.36	0.00
SPASHD	-0.92***	0.45	-0.35	-0.27	0.00
TOTALD	-0.87**	0.46	-0.30	-0.32	0.01
RUNOFD	-0.64	0.05	0.24	0.11	-0.53
WAASHW	-0.93***	0.56	-0.40	-0.25	-0.05
SPASHW	-0.90**	0.63	-0.57	-0.28	0.10
TOTALW	-0.96***	0.63	-0.51	-0.29	0.04
RUNOFW	-0.75*	0.28	-0.09	-0.11	-0.22

TABLE 5-10 (continued)

	AGG	SAND	CLAY	OCC	CRSD
		slope = 3°, n = 38			
WAASHD	-0.76***	0.25	0.07	-0.61***	-0.26
SPASHD	-0.76***	0.38*	-0.06	-0.63***	-0.24
TOTALD	-0.77***	0.38*	-0.04	-0.64***	-0.24
RUNOFD	-0.54***	0.06	0.35*	-0.44**	-0.13
WAASHW	-0.75***	0.22	0.08	-0.60***	-0.27
SPASHW	-0.68***	0.34*	-0.06	-0.60***	-0.24
TOTALW	-0.71***	0.33*	-0.03	-0.62***	-0.25
RUNOFW	-0.57***	0.04	0.24	-0.49**	-0.30
		slope = 10°, n = 45			
WAASHD	-0.58***	0.15	-0.14	-0.44**	0.08
SPASHD	-0.74***	0.27	-0.34*	-0.36*	0.02
TOTALD	-0.74***	0.26	-0.32*	-0.37*	0.02
FUNOFD	-0.23	-0.20	0.11	-0.35*	-0.02
WAASHW	-0.56***	0.15	-0.16	-0.61***	0.02
SPASHW	-0.70***	0.24	-0.32*	-0.35*	0.02
TOTALW	-0.70***	0.23	-0.31*	-0.38**	0.01
RUNOFW	-0.27	-0.03	-0.10	-0.58***	-0.00
		slope = 30°, n = 65			
WAASHD	-0.50***	0.21	-0.35**	-0.54***	-0.07
SPASHD	-0.58***	0.29*	-0.43***	-0.41***	-0.23
TOTALD	-0.57***	0.25*	-0.40***	-0.47***	-0.18
RUNOFD	-0.25*	-0.15	-0.03	-0.47***	-0.18
WAASHW	-0.52***	0.18	-0.36**	-0.58***	-0.21
SPASHW	-0.58***	0.24	-0.36**	-0.23	-0.24*
TOTALW	-0.58***	0.21	-0.37**	-0.41***	-0.24
RUNOFW	-0.25*	-0.05	-0.15	-0.60***	-0.13
	Cultivated, Ap Horizon		slope = 3°, n = 20		
WAASHD	-0.56*	-0.21	0.56**	-0.37	0.05
SPASHD	-0.53*	0.17	0.01	-0.23	-0.04
TOTALD	-0.60**	0.14	0.10	-0.29	-0.08
RUNOFD	-0.42	-0.12	0.63**	-0.48*	0.23
WAASHW	-0.36	-0.27	0.49*	-0.28	-0.14
SPASHW	-0.28	-0.11	0.00	-0.06	-0.30
TOTALW	-0.42	-0.27	0.22	-0.18	-0.27
RUNOFW	-0.28	-0.28	0.51*	-0.28	-0.05

Significance of 'r' : * at 5%; ** at 1%; *** at 0.1%.

TABLE 5-11

DESCRIPTIVE STATISTICS OF SAND CONTENT SUBDIVIDED BY PHYSIOGRAPHIC ZONE, LANDUSE TYPES, & SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	$\bar{x}$	---	36.0	---	---	37.2	32.3	37.0	39.3	38.9
	s	---	---	---	---	8.5	1.9	---	8.7	5.9
	n	---	1	---	---	61	4	1	6	22
B	$\bar{x}$	---	51.0	52.1	48.0	39.2	43.3	51.2	41.5	---
	s	---	4.6	14.5	24.4	10.8	16.5	15.8	0.7	---
	n	---	3	11	3	12	7	5	2	---
C	$\bar{x}$	80.5	---	---	23.8	---	---	38.5	59.0	---
	s	7.0	---	---	3.9	---	---	23.3	---	---
	n	6	---	---	4	---	---	2	1	---

Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated; $\bar{x}$ = sample mean
s = standard deviation; n = sample size.

TABLE 5-12

DESCRIPTIVE STATISTICS OF CLAY CONTENT SUBDIVIDED BY PHYSIOGRAPHIC ZONE, LANDUSE TYPES, & SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	$\bar{x}$	---	8.0	---	---	26.6	23.5	25.0	20.5	23.2
	s	---	---	---	---	7.6	5.9	---	3.1	4.9
	n	---	1	---	---	6.1	4	1	6	22
B	$\bar{x}$	---	19.3	16.6	19.0	27.8	19.0	18.4	24.5	---
	s	---	3.1	5.3	9.6	10.0	6.5	5.9	2.1	---
	n	---	3	11	3	12	7	5	2	---
C	$\bar{x}$	6.3	---	---	30.0	---	---	15.5	14.0	---
	s	2.3	---	---	12.8	---	---	6.4	---	---
	n	6	---	---	4	---	---	2	1	---

Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated; $\bar{x}$ = sample mean; s = standard deviation; n = sample size.

TABLE 5-13a

COEFFICIENTS OF CORRELATION (r)

AMONG SIX SOIL PROPERTY VARIABLES

	AGG	SAND	CLAY	OCC	BKDY	CRSD
AGG	1.00	-0.37***	0.28***	0.14	-0.22**	0.16*
SAND		1.00	-0.70***	-0.31***	0.43***	0.41***
CLAY			1.00	0.28***	-0.33***	-0.29***
OCC				1.00	-0.84***	-0.19*
BKDY					1.00	0.34***
CRSD						1.00

n = 148; significance of 'r' : * 5%, ** 1%, *** 0.1%.

TABLE 5-13b

COEFFICIENTS OF CORRELATION AMONG SIX SOIL PROPERTY VARIABLES FOR THREE TEST SLOPES

	RUNOFT	AGG	SAND	CLAY	OCC	CRSD	TEST SLOPE
RUNOFT	1.00	-0.57***	0.05	0.29	-0.48**	-0.24	3°
	1.00	-0.2[illegible]	-0.09	-0.03	-0.53***	-0.00	10°
	1.00	-0.26*	-0.09	-0.10	-0.56***	-0.16	30°
AGG		1.00	-0.47**	-0.06	0.37*	-0.02	3°
		1.00	-0.41**	0.35*	0.01	0.12	10°
		1.00	-0.36**	0.36**	0.01	0.21	30°
SAND			1.00	-0.35*	-0.22	0.29	3°
			1.00	-0.69***	-0.26	0.49***	10°
			1.00	-0.77***	-0.19	0.32**	30°
CLAY				1.00	0.06	-0.34*	3°
				1.00	0.22	-0.28	10°
				1.00	0.28**	-0.26*	30°
ϕCC					1.00	0.04	3°
					1.00	-0.32*	10°
					1.00	-0.07	30°
CRSD						1.00	3°
						1.00	10°
						1.00	30°

At 3°, n = 38; at 10°, n = 45; at 30°, n = 65; significance of 'r' : * 5%, ** 1%, *** 0.1%.

TABLE 5-14

COEFFICIENTS OF CORRELATION (r) :

PERCENTAGE-WEIGHT WSA > 0.5 mm VS CLAY CONTENT & ORGANIC CARBON CONTENT

CLASSIFICATION		PERCENT CLAY	PERCENT ORGANIC CARBON	SAMPLE SIZE
TEST SLOPE	3°	-0.06	0.37*	38
	10°	0.35*	0.01	45
	30°	0.36**	0.01	65
LANDUSE	Barren	0.01	0.21	21
	Grass	0.41***	-0.25*	86
	Forest	0.62**	0.31	22
	Cultivated	-0.34	0.55**	22
PHYSIOGRAPHIC ZONE, LANDUSE TYPE, & SOIL HORIZON	Mountain, Forest, B horizon	0.45	0.27	11
	Foothills, Grass, A horizon	0.35**	-0.31*	61
ALL SAMPLES		0.28***	0.14	148

TABLE 5-15

COEFFICIENT OF CORRELATION (r) :

PERCENT CLAY VS PERCENTAGE-WEIGHT WSA > 0.5 mm

FOR DIFFERENT RANGES OF ORGANIC CARBON CONTENT

PERCENT ORGANIC CARBON	r	SAMPLE SIZE
0 - 2.25%	-0.05	30
2.25 - 4.0 %	+0.29	26
4.0 - 5.06%	+0.47*	20
5.06 - 7.56%	+0.53***	34
>7.56%	+0.12	38
all samples	+0.28***	148

TABLE 5-16

COEFFICIENT OF CORRELATION (r) :

PERCENT ORGANIC CARBON VS PERCENTAGE-WEIGHT WSA > 0.5 mm

FOR DIFFERENT RANGES OF CLAY CONTENT

PERCENT CLAY	r	SAMPLE SIZE
0 - 17.5%	+0.04	32
17.5 - 22.5%	+0.12	33
22.5 - 27.5%	+0.06	47
>27.5%	+0.15	36
all samples	+0.14	148

TABLE 5-17

BETWEEN RUN VARIATIONS IN BULK DENSITY & MOISTURE CONTENT AND DRY RUN SOIL LOSS OF THREE SELECTED SAMPLES

Sample		Air-Dried Soil	Before Wet Run	Before Run With Vegetation Simulation
CN03	MC(%)	2.2	30.0	29.5
	BD(g/cm^3)	0.85	1.02	1.15
TC35	MC(%)	4.0	42.5	42.3
	BD(g/m^3)	0.71	0.73	0.70
WA04	MC(%)	2.3	30.2	31.4
	BD(g/m^3)	0.99	1.09	1.11

	Soil Type	Dry Soil Loss		
		Wash (g/m^2)	Splash (g/m^2)	Total (g/m^2)
CN08	Mountain B horizon	8	108	116
TC35	Foothills Ah horizon	2	18	20
WA04	Prairies Ap horizon	119	701	820

BD = bulk density; MC = moisture content.

TABLE 6-1

DESCRIPTIVE STATISTICS OF TOTAL LOSS SUBDIVIDED BY TEST SLOPE, PHYSIOGRAPHIC ZONE, & LANDUSE TYPE

Zone		Mountain			Foothills			Plains		
Landuse Type		1	2	3	1	2	3	1	2	4
Test Slope										
3°	$\bar{x}$	---	200	404	64	153	154	---	1001	1216
	s	---	---	256	63	94	---	---	---	349
	n	---	1	2	2	11	1	---	1	20
10°	$\bar{x}$	---	197	450	1206	169	281	---	506	1015
	s	---	19	---	---	145	228	---	338	842
	n	---	2	1	1	30	6	---	3	2
30°	$\bar{x}$	159	404	787	871	324	705	1214	686	---
	s	137	---	395	1089	173	360	314	185	---
	n	6	1	8	4	32	4	8	5	---

$\bar{x}$ = sample mean; s = standard deviation; n = sample size;
Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated; Total Loss in g/m^2.

TABLE 6-2

DESCRIPTIVE STATISTICS OF INDEPENDENT VARIABLES USED IN THE MULTIPLE REGRESSION ANALYSIS

VARIABLE	TRANSFORMATION	$\bar{x}$	s.d.	skewness	minimum	maximum
AGG	SQRT	5.705	1.638	-0.143	1.965	9.391
OCC	SQRT	2.226	0.783	0.065	0.624	3.937
SAND	LOG	1.589	0.127	0.050	1.230	1.886
CLAY	---	23.5	8.2	0.423	6.0	52.0
CRSD	LOG	0.827	0.525	-0.399	-0.523	1.782
RD	---	1.901	3.575	3.383	0.0	23.83
RW	---	3.780	5.877	1.969	0.0	30.47
RT	---	5.681	9.232	2.423	0.0	54.30

$\bar{x}$ = sample mean; s.d. = standard deviation; sample size = 148.

TABLE 6-3

REGRESSION EQUATIONS : SOIL LOSS VARIABLES VS SOIL PROPERTY VARIABLES FOR THREE DIFFERENT SLOPE CATEGORIES

Equation #	D.V.	Constant Term	Partial Regression Coefficients					R^2	n	Remarks
			AGG	OCC	RUNOFF	CLAY	CRSD			
6.3.1	WAASHD	2.672	-0.227	-0.348	0.091		-0.383	0.814	38	θ = 3°
6.3.2.	SPASHD	4.541	-0.237	-0.392	-0.053		-0.327	0.801	38	
6.3.3	TOTALD	4.223	-0.210	-0.349			-0.299	0.786	38	
6.3.4	WAASHW	2.231	-0.184	-0.257	0.093			0.833	38	
6.3.5	SPASHW	3.739	-0.139	-0.261			-0.228	0.662	38	"
6.3.6	TOTALW	3.922	-0.154	-0.280			-0.254	0.711	38	
6.3.7	WAASHT	2.874	-0.209	-0.297	0.046		-0.306	0.843	38	
6.3.8	SPASHT	4.223	-0.167	-0.294			-0.260	0.725	38	
6.3.9	TOTALT	4.349	-0.177	-0.308			-0.276	0.756	38	
6.3.10	WAASHD	2.046	-0.174	-0.209	0.118			0.658	45	θ = 10°
6.3.11	SPASHD	3.825	-0.240	-0.224				0.675	45	
6.3.12	TOTALD	3.865	-0.238	-0.233				0.677	45	
6.3.13	WAASHW	2.719	-0.188	-0.305	0.067			0.767	45	
6.3.14	SPASHW	3.986	-0.225	-0.214				0.607	45	"
6.3.15	TOTALW	4.131	-0.229	-0.245				0.626	45	
6.3.16	WAASHT	2.794	-0.184	-0.271	0.044			0.776	45	
6.3.17	SPASHT	4.212	-0.230	-0.217				0.641	45	
6.3.18	TOTALT	4.316	-0.232	-0.239				0.652	45	
6.3.19	WAASHD	2.525	-0.087	-0.122	0.056	-0.009		0.758	65	θ = 30°
6.3.20	SPASHD	3.006	-0.113	-0.100	0.025	-0.009		0.575	65	
6.3.21	TOTALD	3.132	-0.107	-0.110	0.038	-0.008		0.675	65	
6.3.22	WAASHW	2.671	-0.110	-0.119	0.036			0.809	65	
6.3.23	SPASHW	2.779	-0.115		0.016			0.439	65	"
6.3.24	TOTALW	2.920	-0.111		0.028			0.630	65	
6.3.25	WAASHT	2.910	-0.095	-0.108	0.023	-0.006		0.808	65	
6.3.26	SPASHT	3.090	-0.101		0.012	-0.203		0.527	65	
6.3.27	TOTALT	3.220	-0.095		0.018	-0.008		0.668	65	

D.V. = dependent variable; R^2 = coefficient of determination; n = sample size.

TABLE 6-4

SIXTH ORDER PARTIAL CORRELATION COEFFICIENT : THREE SELECTED SOIL LOSS VARIABLES VS EIGHT SLOPE FUNCTIONS†

	θ	$\sin\theta$	$\sin\theta\cos\theta$	$\tan\theta$	$\frac{\cos\theta}{\tan^{0.3}\theta}$	$\log(\sin\theta)$	$\log(\sin\theta\cos\theta)$	$\log(\tan\theta)$
WAASHT	0.774***	0.773***	0.771***	0.775***	0.766***	0.726***	0.716***	0.734***
SPASHT	-0.021	-0.021	-0.023	-0.019	-0.026	-0.035	-0.037	-0.034
TOTALT	0.213*	0.212*	0.208*	0.215*	0.203*	0.176*	0.170*	0.180*

† Partial correlation with the following variables controlled for : RUNOFT, AGG, SAND, CLAY, OCC, CRSD

Significance of 'r' : * at 5%, ** at 1%, *** at 0.1%.

TABLE 6-5

REGRESSION EQUATIONS : SOIL LOSS VARIABLES VS SLOPE & SOIL PROPERTY VARIABLES

Equation #	D. V.	Constant Term	Regression Coefficients							R^2	n
			AGG	OCC	RUNOFF	CLAY	CRSD	tanθ	log tanθ		
6.5.1	WAASHD	3.587	-0.217	-0.298	0.058				1.043	0.798	148
6.5.2	SPASHD	3.833	-0.203	-0.259			-0.139			0.689	148
6.5.3	TOTALD	3.748	-0.199	-0.256	0.021					0.708	148
6.5.4	WAASHW	3.679	-0.210	-0.282	0.044				0.900	0.814	148
6.5.5	SPASHW	3.586	-0.163	-0.176			-0.113			0.573	148
6.5.6	TOTALW	3.512	-0.158	-0.174	0.019					0.660	148
6.5.7	WAASHT	3.941	-0.212	-0.291	0.025				0.937	0.820	148
6.5.8	SPASHT	3.991	-0.180	-0.210			-0.127			0.638	148
6.5.9	TOTALT	3.891	-0.174	-0.203	0.011					0.692	148
6.5.10	WAASHT	2.548	-0.192	-0.256	0.025			1.803		0.842	148
6.5.11	WAASHT	2.498	-0.159	-0.255	0.025		-0.146	1.827		0.848	143
6.5.12	SPASHT	3.998	-0.140	-0.180		-0.009	-0.215			0.639	143
6.5.13	TOTALT	3.847	-0.128	-0.157	0.012		-0.177	0.198		0.719	143
6.5.14	WAASHT	3.696	-0.160	-0.247	0.020				1.286	0.877	126
6.5.15	SPASHT	3.600	-0.162	-0.156	0.006					0.546	126
6.5.16	TOTALT	4.139	-0.179	-0.236					0.201	0.635	126
6.5.17	TOTALT	3.825	-0.161	-0.167	0.012				0.200	0.670	126
6.5.18	TOTALT	3.741	-0.163	-0.126	0.021				0.295	0.646	91

D.V. = dependent variables; R^2 = coefficient of determination; n = sample size.

TABLE 6-6

REGRESSION EQUATIONS : THIRD RUN SOIL LOSS VARIABLES VS COVER DENSITY AND SOIL VARIABLES

Equation #	D.V.	Constant Term	Regression Coefficients				R^2	n	Remarks
			COVER	AGG	OCC	CLAY			
5.8.1	WAASHV	1.278	1.059	-0.198	-0.359		0.753	23	$\theta = 3^\circ$
5.8.2	SPASHV	1.179	1.068		-0.291		0.885	23	$\theta = 3^\circ$
5.8.3	TOTALV	1.216	1.106		-0.301		0.888	23	$\theta = 3^\circ$
5.8.4	WAASHV	0.326	0.985	-0.142			0.530	32	$\theta = 10^\circ$
5.8.5	SPASHV	1.030	1.163		-0.140	-0.015	0.862	32	$\theta = 10^\circ$
5.8.6	TOTALV	1.361	1.097	-0.058	-0.144	-0.010	0.869	32	$\theta = 10^\circ$
5.8.7	WAASHV	0.348	0.839			-0.017	0.545	41	$\theta = 30^\circ$
5.8.8	SPASHV	0.723	0.904			-0.013	0.762	41	$\theta = 30^\circ$
5.8.9	TOTALV	0.879	0.886			-0.013	0.733	41	$\theta = 30^\circ$

D.V. = dependent variable; R^2 = coefficients of determination; n = sample size.

TABLE 6-7

REGRESSION EQUATIONS : THIRD RUN SOIL LOSS VARIABLES VS COVER DENSITY, SLOPE, AND SOIL PROPERTY VARIABLES

Eq #	D.V.	Constant Term	Regression Coefficients							R^2	n
			COVER	AGG	OCC	CLAY	CRSD	tanθ	log(tanθ)		
6.7.1	WAASHV	1.372	0.935	-0.152	-0.224				0.462	0.663	96
6.7.2	SPASHV	1.325	0.932	-0.064	-0.161	-0.009			-0.190	0.872	96
6.7.3	SPASHV	1.252	0.929	-0.085	-0.169				-0.160	0.856	96
6.7.4	SPASHV	1.401	0.933	-0.010	-0.154					0.842	96
6.7.5	TOTALV	1.699	0.925	-0.080	-0.163	-0.009	-0.096			0.863	96
6.7.6	WAASHV	0.757	0.910	-0.139	-0.215			0.760		0.654	96
6.7.7	SPASHV	1.597	0.944	-0.066	-0.169	-0.010		-0.374		0.876	96
6.7.8	TOTALV	1.659	0.943	-0.073	-0.171	-0.009		-0.236		0.865	96
6.7.9	SPASHV	1.414	0.811	-0.092	-0.140					0.729	82
6.7.10	TOTALV	1.572	0.817	-0.097	-0.158					0.744	82

D.V. = dependent variable; R^2 = coefficients of determination; n = sample size.

TABLE 6-8

REGRESSION EQUATIONS : CORRECTED SOIL LOSS VARIABLES VS SLOPE
AND SOIL PROPERTIES VARIABLES

Equation #	Dependant Variable	Constant Term	Regression Coefficients							
			AGG	OCC	CRSD	Log (sinθcosθ)	RUNOFF	(Tanθ)	R^2	n
6.8.1	log(CSD)	3.916	-0.206	-0.271	-0.125	0.236			0.692	148
6.8.2	log(CSW)	3.688	-0.167	-0.186	-0.104	0.256			0.586	148
6.8.3	log(CST)	4.080	-0.183	-0.221	-0.114	0.242			0.646	148
6.8.4	log(CTD)	3.911	-0.206	-0.259		0.320	0.022		0.725	148
6.8.5	log(CTW)	3.705	-0.168	-0.169		0.351	0.020		0.697	148
6.8.6	log(CTT)	4.070	-0.183	-0.202		0.333	0.012		0.718	148
6.8.7	log(CTD)	3.862	-0.206	-0.253			0.022	0.292	0.729	148
6.8.8	log(CTW)	3.646	-0.167	-0.166			0.020	0.315	0.701	148
6.8.9	log(CTT)	4.016	-0.182	-0.199			0.012	0.301	0.722	148

CSD, CSW, CST = corrected splash loss, dry run, wet run, and total respectively;
CTD, CTW, CTT = corrected total loss, dry run, wet run and total run respectively;
D.V = dependent variable; R^2 = coefficient of determination; n = sample size.

TABLE 7-1

PLOT CHARACTERISTICS

PLOT #	BASIN & UNIT	PARENT MATERIAL	GEOMORPHIC POSITION	SLOPE	ASPECT	COVER	SOIL TYPE	SOIL TEXTURE
C1	Cataract : South	Blairmore Sandstone	Upper mid-slope above creek	29.25°	134°	Engelmann spruce some jack pines	Brown-Wooded	Sandy loam
C2	Cataract : South	Fernie Shale	Mid-slope on cut-bank above creek	34.25°	260°	Grass	Regosol	Loam
C3	Cataract : Central	Blairmore Sandstone	Mid-slope above creek	26°	234°	Engelmann spruce & pines	Brown-Wooded	Sandy loam
C4	Cataract : North	Blairmore Sandstone	Upper part of slumping scar above creek	34.75°	164°	Barren	Brown-Wooded B + C horizon	Sandy clay loam
C5	Cataract : North	Blairmore Sandstone	Lower-slope above 'hangmoor'	20°	209°	Engelmann spruce	Brown-Wooded	Sandy loam
C6	Cataract : North	Upper Alberta Shale	Mid-slope above creek	18.5°	24°	Engelmann spruce	Brown-Wooded	Sandy clay loam
P2	Pekisko : Cartwright	Upper Alberta Silty Shale	Lower slope above creek	24.1°	220°	Grass	Eroded Thin Black	Silty loam
P3	Stimson : Spruce Ranching	Belly River Sandstone	Upper slope near ridge top	16.75°	87°	Grass	Regosol	Loam
P4	Stimson : Spruce Ranching	Belly River Sandstone	Mid-slope below sandstone rock face	14°	219°	Grass	Thin Black	Loam
P5	Stimson : Blades	Paskapoo Sandstone	Mid-slope above terrace	16.5°	216°	Grass	Black Chernozem	Loam
P7	Stimson : Smith	Belly River Sandstone	Lower slope	19.25°	230°	Grass	Thin Black	Loam
P8	Stimson : Smith	Sand and gravel	Lower slope above terrace	18.5°	65°	Poplar	Brown-Wooded	Loam

TABLE 7-1 (cont'd)

PLOT #	BASIN & UNIT	PARENT MATERIAL	GEOMORPHIC POSITION	SLOPE	ASPECT	COVER	SOIL TYPE	SOIL TEXTURE
T1	Three Point : Ware Southwest	Blairmore Sandstone	On lower slope before sandstone outcrop	22.5°	178°	Pine	Brown-wooded	Sandy loam
T2	Three Point : McMurtry	Till	Open benchland above lake basin	7°	248°	Grass	Thin Black	Clay
T3	Three Point : Charmes	Belly River Sandstone	Upper slope above terrace	20.75°	119°	Grass	Thin Black	Clay loam
T4	Three Point : Charmes	Belly River Sandstone	Mid-slope above terrace close to sandstone outcrop	26.25°	178°	Grass	Degraded Black	Sandy clay loam
T5	Three Point : Northfork East	Belly River Sandstone & interbedded shale	Upper slope below narrow upland bench	26°	147°	Grass	Regosol	Clay loam
T6	Three Point : Northfork East	Belly River Sandstone & interbedded shale	Upper slope below narrow upland bench	19.5°	240°	Poplar	Brown-Wooded	Loam
T7	Three Point : Northfork West	Alberta Sandstone	Slope base above colluvial fan	23.75°	136°	Grass adjacent to spruce/pine	Degraded Brown-Wooded	Loam
T8	Three Point Northfork West	Alberta Sandstone	Mid-slope above fan	18.5°	155°	Pine stands	Brown-Wooded	Sandy loam
W1	West Arrowwood : Campbell	Thin Resorted Till	Mid-slope above creek	14.75°	246°	Grass	Dark Brown Chernozem	Silty clay loam
W3	West Arrowwood : Merkel	Resorted Till	Upper slope above creek	16.5°	45°	Grass	Dark Brown Chernozem	Silty loam
W5	West Arrowwood : Andrews	Resorted Till	Upper slope	17.75°	247°	Grass	Dark Brown Chernozem	Silty loam
W6	West Arrowwood : Steiner	Resorted Till	Mid-slope above coulee	16.5°	251°	Grass	Dark Brown Chernozem	Loam
W7	West Arrowwood : Steiner	Resorted Till	Upper slope above coulee	16°	88°	Grass	Dark Brown Chernozem	Loam
W8	West Arrowwood : Weber	Resorted Till	Lower slope above coulee	15.25°	248°	Grass	Dark Brown Chernozem	Loam

*Four plots where there are no valid soil loss data sets available are excluded from this table.

TABLE 7-2

SOIL LOSS, RAINFALL, AND COVER DENSITY DATA, 1973

Plot #	Period	Soil Loss (g/m^2)	Rainfall Amount (mm)	Bare Ground (%)
C1	Jun 30 - Oct 7	3.54	148	0.25
*C2	Jun 30 - Oct 7	6.32	148	5.00
C3	Jun 30 - Oct 7	8.34	153	0.25
*C4	Jul 3 - Oct 7	167.39	159	57.50
C5	Jul 3 - Oct 7	46.67	159	20.00
C6	Jul 3 - Oct 7	8.22	159	0.25
P3	May 21 - Jul 19	7.28	150	0.25
P3	Jul 21 - Oct 8	1.38	170	0.25
*P4	May 21 - Jul 19	1.24	150	0.50
P4	Jul 19 - Oct 7	0.74	170	0.50
*P5	May 21 - Jul 19	9.77	141	4.50
P5	Jul 19 - Oct 7	5.63	160	4.50
P7	May 20 - Jul 19	12.16	156	1.60
P8	May 20 - Jul 19	1.14	156	0.25
P8	Jul 19 - Oct 7	2.02	151	0.25
*T1	Jun 29 - Oct 6	6.42	241(E)	0.25
T2	Apr 24 - Jun 28	8.80	143	5.00
*T3	Jun 4 - Jul 22	1.92	83	4.00
T3	Jul 22 - Oct 8	7.05	176	4.00
*T4	Apr 24 - Jul 22	6.78	192	14.00
T4	Jul 23 - Oct 8	12.82	160	14.00
T6	Jun 29 - Oct 6	6.75	233	0.25
*T7	Jun 29 - Oct 6	10.62	254(E)	5.00
T8	Jun 29 - Oct 6	13.41	254(E)	0.25
*W1	Apr 21 - Jun 16	21.39	100	37.40
*W3	Apr 22 - Jul 20	5.63	141	2.50
W3	Jul 20 - Oct 8	3.38	125	2.50
*W5	Apr 21 - Jul 20	18.37	142(E)	19.00
*W6	Apr 21 - Jun 16	21.95	66(E)	10.60
*W7	Apr 20 - Jun 16	5.35	66(E)	7.90
*W8	Apr 22 - Jul 20	14.56	139	0.25
W8	Jul 20 - Oct 8	1.24	121	0.25

*Plots maintained in 1974 season. (P2 and T5 not listed); (E) estimated.

TABLE 7-3

SOIL LOSS DATA 1974

PLOT	1	2	3	4	5	6
C2	-	-	-	-	4.63	2.89
C4	-	-	< 50.80 >		16.45	22.71
P2	-	0.66	0.92	5.11	0.92*	10.23*
P4	-	0.62	0.62	0.74	3.94*	-
P5	-	4.62	10.23	6.49	7.73*	7.98*
T1^{f}	-	-	2.85	2.22	13.46*	-
T3	-	0.64	0.51	0.51	2.69*	2.17*
T4	-	-	1.20	1.33	2.27*	2.13*
T5	-	< 2.00 >		2.53	1.33*	1.33*
T7^{f}	-	-	-	5.99	9.28*	9.15*
W1	27.95	1.24	1.48	18.43	2.47	1.24
W3	10.48	0.87	0.87	2.99	2.00*	5.24*
W5	13.06	1.51	-	2.01	2.26	0.63
W6	48.40	2.25	2.62	36.30	3.49	5.49
W7	18.79	2.36	2.99	-	-	-
W8	4.46	2.11	1.86	5.33	4.96*	3.97*

Soil loss in g/m^2; Periods : 1 = April 25 - May 8; 2 = May 8 - May 26/27; 3 = May 26/27 - June 16/17; 4 = June 16/17 - July 16/17; 5 = July 16/17 - August 13/14; 6 = August 13/14 - September 21/22;

*data affected by partial clipping of vegetation; f = forested sites.

TABLE 7-4

RAINFALL DATA 1974

PLOT	1	2	3	4	5	6
C2	-	-	-	-	53.1	37.6
C4	-	-	← 52.1 →		48.0	36.1
P2	-	13.2	41.1	56.6	90.2	65.8
P4	-	53.3	24.9	36.8	89.2	-
P5	-	54.9	30.7	51.6	83.6	69.3
T3	-	34.3	21.6	37.3	72.9	38.9
T4	-	-	21.6	37.3	72.9	38.9
T5	-	80.0	34.3	86.6	46.0	46.0
W1	81.8	39.1	9.4	63.8	35.6	17.8
W3	99.6	38.9	13.0	60.5	36.1	19.0
W5	-	42.9	-	48.8	38.9	10.9
W6	79.0	39.0	25.1	72.1	39.6	13.5
W7	79.0	39.0	25.1	-	-	-
W8	93.2	43.9	10.7	60.2	45.2	18.0

Rainfall amount in mm; Period same as Table 7-3

TABLE 7-5

COMPARISON OF NORMAL AND 1973 & 1974 FIELD SEASON PRECIPITATION FOR FOUR SELECTED STATIONS

Year	Station	Apr	May	Jun	Jul	Aug	Sep	Total
1973	Gleichen	37.8	8.1	81.8	11.7	72.9	21.3	233.7
	Turner Valley	63.8	72.1	67.1	35.1	174.8	50.3	463.0
	Pekisko	90.4	71.6	79.5	30.7	123.7	16.8	412.8
	Kananaskis	67.3	84.8	62.0	28.4	97.3	N.A.	N.A.
1974	Gleichen	58.2	49.3	36.6	43.4	48.5	7.6	243.6
	Turner Valley	58.9	100.1	16.3	68.1	83.6	61.5	388.4
	Pekisko	119.1	98.3	64.8	27.9	117.3	72.6	500.1
	Kananaskis	104.4	171.7	28.4	30.2	100.6	43.9	479.3
NORMAL	Gleichen	29.5	44.2	83.6	55.9	48.0	32.8	293.9
	Turner Valley	52.1	73.2	119.6	67.3	73.2	44.7	430.0
	Pekisko	67.8	85.9	131.8	55.4	63.5	59.4	463.8
	Kananaskis	63.0	81.5	115.6	64.3	70.1	52.1	446.6

Rainfall amounts in mm.

TABLE 7-6

COVER DENSITY DATA, 1974

PLOT	1	2	3	4	5	6
C2	-	-	-	-	1.50	0.5
C4	-	-	-	-	45	35
P2	-	3.0	2.25	2.0	4.25	3.0
P4	-	0.25	0.25	0.25	10.25	-
P5	-	3.5	3.5	4.5	16.5	12.75
T1	-	← 0.25 →		0.25	92.5	-
T3	-	2.5	1.5	1.0	22.0	22.5
T4	-	4.5	3.75	4.5	14.75	14.5
T5	-	- 6.5 -		2.75	12.25	10.0
T7	-	← →		2.25	80.5	71.0
W1	15.5	11.5	3.5	3.5	5.25	6.0
W3	1.0	0.75	0.5	0.5	7.5	9.5
W5	9.0	8.0	5.75	6.75	5.75	4.0
W6	16.25	18.0	12.75	14	15.5	13.75
W7	17.75	20.75	23.25	19.5	-	-
W8	3.5	1.25	1.0	0.75	12	8.75

Bare ground in percent; Periods as in Table 7-3

TABLE 7-7

SOIL MOISTURE DATA, 1974

Plot	Apr 25	May 7/8	May 26/27	Jun 16/17	Jul 16/17	Aug 13/14	Sep 21/22
C2	-	-	-	-	11.8	20.6	16.0
C4	-	-	11.8	-	4.8	14.3	7.0
P2	-	31.4	36.6	12.8	7.0	28.3	16.9
P4	-	35.4	34.2	20.3	10.8	34.8	-
P5	-	31.3	-	7.1	5.9	30.1	12.2
T1	-	24.0	-	13.8	9.8	-	-
T3	-	28.5	29.2	9.9	7.2	32.5	14.0
T4	-	21.7	15.4	6.2	4.8	29.2	6.6
T5	-	-	-	7.3	6.8	28.3	13.3
T7	-	-	-	7.5	9.5	-	19.4
W1	9.8	23.0	21.5	10.3	10.8	34.1	8.7
W3	10.2	29.7	23.0	6.9	8.7	28.3	6.6
W5	7.3	27.6	21.9	7.2	5.6	30.1	5.2
W6	20.2	29.0	21.2	8.9	9.9	30.9	7.7
W7	15.4	26.9	21.8	6.0	11.4	-	-
W8	14.3	27.4	17.8	6.4	7.7	28.5	5.8

Wet base soil moisture content in %; each data point is an average of 5 samples.

TABLE 7-8

SOIL PROPERTIES DATA

Plot #	% - Wt. WSA 0.5 mm (%)	ORG CARBON (%)	SAND (%)	SILT (%)	CLAY (%)	SAND 0.5 - 4 mm (%)	BULK DENSITY (g/c^3)
C2	19.3	1.7	46	36	18	56.3	1.09
C4	38.9	1.9	57	16	27	34.0	1.27
P2	35.7	8.7	24	48	28	19.2	1.19
P3	43.2	6.4	40	29	31	5.7	1.01
P4	41.4	10.2	46	29	26	11.0	0.97
P5	29.1	9.9	43	32	26	16.2	1.11
P7	19.0	11.0	39	39	22	14.1	1.21
T2	52.9	8.3	11	38	51	1.5	1.04
T3	50.6	8.7	22	40	38	4.6	0.93
T4	24.5	7.0	46	25	29	7.3	1.10
T5	39.7	5.0	32	38	30	16.0	1.19
W1	33.1	7.8	17	51	32	0.6	1.05
W3	10.9	5.5	24	49	27	0.9	1.26
W5	10.8	7.1	22	54	24	1.1	1.24
W6	29.2	5.8	34	42	24	1.6	1.26
W7	18.5	4.5	49	32	19	1.0	1.29
W8	12.2	5.7	34	39	27	4.1	1.23

TABLE 7-9

COEFFICIENTS OF CORRELATION FOR ALL VARIABLES
USED IN THE STATISTICAL ANALYSIS,
PLOT PERIOD DATA 1974

	SOILOS	RAIN	COVER	AGG	OCC	SAND	CLAY	BKDY	CRSD	SINCOS
SOILOS	1.00	0.44	0.53	-0.19	-0.36	0.31	-0.33	0.40	0.16	0.00
RAIN		1.00	0.19	0.12	0.01	0.17	-0.05	-0.01	0.16	0.11
COVER			1.00	0.11	-0.27	0.18	-0.02	0.28	-0.05	0.20
AGG				1.00	0.37	0.02	0.59	-0.66	0.23	0.29
OCC					1.00	-0.30	0.41	-0.62	-0.34	-0.43
SAND						1.00	-0.51	0.13	0.49	0.28
CLAY							1.00	-0.61	-0.26	0.08
BKDY								1.00	-0.06	0.05
CRSD									1.00	0.71
SINCOS										1.00

SOILOS = Double-log soil loss in g/m^2; RAIN = rainfall amount in mm; SINCOS = $\sin\theta \times \cos\theta$; significance of 'r' values : for $r \geqslant \pm 0.25$, $p \leqslant 0.05$; for $r \geqslant \pm 0.32$, $p \leqslant 0.01$; for $r \geqslant \pm 0.41$, $p \leqslant 0.001$; n = 63.

TABLE 7-10

REGRESSION EQUATIONS : SOIL LOSS VS ALL VARIABLES, PERIOD & SEASON DATA SETS

		Partial Regression Coefficients										
Equation	D.V.	C_T	Log	Log	Cy	G	C	BD	Log (sinθ cosθ)	R^2	n	Remarks
7.10.1	DL(SL)	0.019	0.12	0.20	-0.0098					0.50	63	All 1974 period Data
7.10.2	DL(SL)	-0.20	0.12	0.22		-0.0035				0.49	63	
7.10.3	DL(SL)	-0.14	0.11	0.22		-0.026	-0.012			0.51	63	
7.10.5	DL(SL)	-0.20	0.11	0.23		-0.0038				0.49	58	Foothills + Plains
7.10.6	DL(SL)	-0.55	0.12	0.23		-0.0028			-0.57	0.57	58	Foothills + Plains
7.10.7	DL(SL)	-0.10	0.09	0.22		-0.0063				0.60	27	Foothills only
7.10.8	DL(SL)	-0.29	0.07	0.26						0.46	31	Plains only
7.10.9	DL(SL)	-0.19	0.12	0.22		-0.0043				0.60	26	Period 1 - 3
7.10.10	DL(SL)	0.12	0.12	0.17	-0.012					0.43	37	Period 4 - 6
7.10.11	DL(SL)	-0.33	0.086	0.13				0.26		0.56	29	1973 & 1974 season data
7.10.12	DL(SL)	-2.14	0.43	0.67				1.28		0.56	29	

DL(SL) = log (log(SL x 10)); C_T = Constant Term

TABLE 7-11

SEASON SOIL LOSS, MEAN COVER DENSITY & TOTAL SEASON RAINFALL, 1973 & 1974.

PLOT #	SEASON SOIL LOSS (g/m^2)	RAINFALL AMOUNT (mm)	BARE GROUND (%)
	1973 DATA		
C2	3.53	147.8	0.3
C4	167.35	158.7	57.5
P3	8.60	319.5	0.3
P4	1.96	319.5	0.5
P5	15.39	300.7	4.5
P7	12.18	156.0	1.6
T2	8.77	143.3	5.0
T3	9.00	259.1	4.0
T4	21.10	351.6	14.0
W1	21.41	99.6	37.4
W3	9.00	266.5	2.5
W5	18.33	141.7	19.0
W6	21.90	66.0	10.6
W7	5.31	66.0	7.9
W8	15.81	260.4	0.3
	1974 DATA		
C2	7.52	90.7	1.0
C4	89.95	136.1	50.0
P2	10.22 *	267.0	3.0
P4	5.92 *	204.2	2.8
P5	37.05 *	290.1	7.9
T3	6.52 *	205.0	9.9
T4	6.94 *	166.1	9.4
T5	7.19 *	246.9	7.0
W1	52.81	246.9	7.5
W3	21.20 *	267.0	3.3
W5	6.40	141.5	6.1
W6	98.54	278.4	15.0
W7	24.13	153.2	20.6
W8	22.69 *	271.3	4.5

* Data affected by partial clipping of vegetation cover.

TABLE 7-12

COEFFICIENTS OF CORRELATION FOR ALL VARIABLES USED IN PLOT-SEASON DATA ANALYSIS

	DL(SL)	Log (Rf)	Log (K)	G	C	Sd	Cy	Bd	Cs	Log (sinθcosθ)
DL(SL)	1.00	0.03	0.64	-0.06	-0.24	0.06	0.01	0.46	-0.46	0.12
Log(Rf)		1.00	-0.28	0.14	0.39	-0.09	0.26	-0.28	-0.18	-0.04
Log(K)			1.00	0.11	-0.11	0.00	0.12	0.32	-0.22	0.11
G				1.00	0.28	-0.07	-.67	-0.66	0.03	-0.13
C					1.00	-0.38	-.37	-0.49	-0.52	-0.50
Sd						1.00	-0.59	0.19	0.53	0.51
Cy							1.00	-0.52	-0.37	-0.47
Bd								1.00	-0.05	0.17
Cs									1.00	0.64
Log(sinθcosθ)										1.00

Significance of 'r' values : for $r \geq \pm 0.137$, $p \leq 0.05$; for $r \geq \pm 0.47$; $p \leq 0.01$; for $r \geq \pm 0.58$, $p \leq 0.0001$; $n = 29$.

TABLE 8-1a

CLASSIFICATION OF SOIL ERODIBILITY (CORRECTED FOR SPLASH)

BY PHYSIOGRAPHIC ZONE, LANDUSE TYPES, AND SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	$\bar{x}$	---	204	---	---	205	180	1027	517	1305
	n		(1)			(61)	(4)	(1)	(6)	(22)
B	$\bar{x}$	---	236	628	239	241	494	1004	785	---
	n		(3)	(11)	(3)	(12)	(7)	(5)	(2)	
C	$\bar{x}$	144	---	---	937	---	---	1378	781	---
	n	(6)			(4)			(2)	(1)	
Sample		144	228	628	637	211	380	1100	606	1305
Mean		Mountain : 414			Foothills : 264			Plains : 1102		
				Grand Mean : 501						

$\bar{x}$ = grouped mean soil erodibility in g/m^2; n = sample size;
Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated.

TABLE 8-1b

CLASSIFICATION OF SOIL ERODIBILITY (UNCORRECTED) BY PHYSIOGRAPHIC ZONE, LANDUSE TYPES, AND SOIL HORIZON

Horizon		Mountain			Foothills			Plains		
		1	2	3	1	2	3	1	2	4
A	x̄	---	217	---	---	224	217	973	529	1901
	n		(1)			(61)	(4)	(1)	(6)	(22)
B	x̄	---	263	596	233	234	506	951	827	---
	n		(3)	(11)	(3)	(12)	(7)	(5)	(2)	
C	x̄	136	---	---	959	---	---	1197	998	---
	n	(6)			(4)			(2)	(1)	
Sample		136	251	596	648	226	401	1015	647	1901
Mean		Mountain : 399			Foothills : 280			Plains : 1430		
					Grand Mean : 593					

x̄ = grouped mean soil erodibility in g/m^2; n = sample size;
Landuse Types : 1 = barren; 2 = grass; 3 = forest; 4 = cultivated.

TABLE 8-2a

COEFFICIENTS OF CORRELATION : PREDICTED VS OBSERVED SOIL LOSS

	PLOT-PERIOD DATA (n = 63)		PLOT-SEASON DATA (n = 29)	
	PSL1	PSL2	PSL1	PSL2
OSL1	0.53	0.53	0.74	0.73
OSL2	0.55	0.53	0.74	0.69
OSL3	0.55	0.52	0.69	0.64

All 'r' values significant at the 0.1% level.

TABLE 8-2b

POLYNOMIAL EQUATIONS RELATING PREDICTED AND OBSERVED SOIL LOSS, PLOT-PERIOD DATA

Dependent Variable (y)	Independent Variable (x)	Polynomial Equation	R
PSL1 x 10^3	OSL1 x 10	$y = -9.92 + 17.36x - 8.42x^2 + 1.36x^3$	0.62
PSL2 x 10^3	OSL1 x 10	$y = -10.21 + 17.14x - 8.16x^2 + 1.30x^3$	0.61
PSL1 x 10^3	OSL2 x 10	$y = -7.97 + 9.59x - 3.08x^2 + 0.33x^3$	0.63
PSL2 x 10^3	OSL2 x 10	$y = -7.43 + 9.38x - 3.05x^2 + 0.33x^3$	0.66

TABLE 8-3

WEIGHTED MEAN SOIL ERODIBILITY, MEAN COVER DENSITY, SLOPE, AND EROSION POTENTIAL OF SAMPLED UNITS

UNIT	MEAN PINDEX	MEAN TOTALP (g/m^2)	MEAN BARE GROUND (%)	MEAN SLOPE (°)	EROSION POTENTIAL (g/m^2)
CC	52.3	559	3.7	18.1	25.8
CN	52.2	558	5.5	18.7	37.4
CS	44.1	471	3.2	17.6	17.5
PB	16.0	171	3.5	9.5	6.2
PC	23.0	246	5.0	9.8	12.4
PR	19.9	213	3.2	12.5	7.7
PS	28.2	301	3.3	18.9	12.6
TC	16.7	179	7.0	7.0	11.1
TE	19.6	210	2.8	7.7	5.7
TM	18.4	197	12.4	6.1	19.8
TN	40.2	430	2.5	24.3	14.9
TW	19.6	210	2.9	14.9	7.3
WA	132.7	1419	68.7	3.4	573.6
WC	96.9	1036	40.4	5.9	307.0
WM	119.2	1274	48.6	4.1	397.8
WS	135.6	1450	52.1	4.0	490.7
WW	83.4	892	58.7	3.3	308.6

TABLE 8-4

DATA & COMPUTATION OF GROSS EROSION RATE OF SELECTED BASINS

Basin	Soil Erodibility (g/m^2)	Mean Bare Ground (%)	Mean Slope (%)	I (mm)	A (mm)	R.E.	S.E.P.	G.E.R.
Cataract Creek	49.5	2.3	21.5	38.1	279	41	30.9	100
West Arrowwood Creek	113.6	47.2	1.3	40.6	292	48	26.8	335
Three Point Creek	22.9	7.7	14.9	43.2	381	71	27.3	187
Pekisko Creek	23.0	6.5	10.7	50.8	381	98	14.5	157
Stimson Creek	21.4	6.8	6.8	48.3	356	83	7.4	82

I = mean annual maximum 24 hr rainfall intensity; A = mean annual rainfall;

R.E. = Rainfall Erosivity = $I^2 \times A$; S.E.P. = Soil Erosion Potential computed by Equation # 8.10;

G.E.R. = Gross Erosion Rate = $S.E. \times (\theta)^{1.0} \times (K)^{1.0} \times (R.E.)^{1.0} \times 10^{-3}$.

TABLE 9-1

AVAILABLE SEDIMENT YIELD & DISCHARGE DATA IN STUDY AREA

Drainage Basin	Area (km^2)	Estimated Suspended Sediment Yield (m-tons/km^2)	Total Suspended Sediment Yield (m-tons)	Mean Annual Unit Discharge ($m^3 \times 10^6/km^2$)	Mean Annual Discharge[d] ($m^3 \times 10^6$)
CATARACT CREEK near Forestry Road	165	30.1[a]	4 967	0.439	72.4
HIGHWOOD RIVER below Picklejar Creek	130	14.9[a]	1 937	1.030	133.94
HIGHWOOD RIVER at Diebel's Ranch	777	23.7[a]	18 415	0.540	419.66
THREE POINT CREEK near Millarville	499	127[a]	63 373	0.200	100.00
PEKISKO CREEK near Longview	192	47 - 75[b]	9 024 - 14 400	0.261	50.09
STIMSON CREEK near Pekisko	239	17.3[a]	4 135	0.136	32.59
HIGHWOOD RIVER near the mouth	3 989	44.9[c]	88 821 - 269 264	0.168	671.46
WEST ARROWWOOD CREEK near Arrowwood	685	30 - 50[b]	20 550 - 34 547	0.035	23.66
BOW RIVER at Calgary	7 770	6.4[c]	64 164 - 35 547	0.377	2 930.49
BOW RIVER below Bassano Dam	19 710	11.3[c]	101 343 - 345 692	0.287	5 660.98

[a] McPherson (1975); [b] Pekisko Creek was estimated from suspended sediment samples published in Preliminary Sediment Data, Water Survey of Canada and others available from Abrahams & McPherson (1972); West Arrowwood Creek rate estimated from other prairie watershed data published in McPherson (1975); [c] Only average rates from 2 years' data 1972 and 1973, Preliminary Data available from Water Survey of Canada; [d] data published in Historical Streamflow Summary, Alberta, to 1973, Water Survey of Canada, Environment Canada (1974).

TABLE 9-2

SEDIMENT YIELD BY PHYSIOGRAPHIC ZONE IN STUDY AREA BASED ON LABORATORY AND FIELD DATA

Zone	Area (km^2)	Suspended Sediment Yield (m-tons/km^2)	Total Yield (10^3 m-tons)
Mountain	796	20 - 30	16 - 24
Upper Foothills	1 005	40 - 80	40 - 101
Lower Foothills	2 428	20 - 60	48 - 146
Plains	5 771	30 - 50	173 - 289
TOTAL/MEAN	10 000	28 - 56	277 - 560

TABLE 9-3

SEDIMENT SOURCES & SEDIMENTATION RATE AT BASSANO DAM

	Source	Sediment Yield (10^3 m-tons)	Total (10^3 m-tons)
Sediment input	Bow at Calgary	36 - 64[a]	452 - 1 044
	Highwood near the Mouth	89 - 270[a]	
	Prairie watersheds	277 - 560[b]	
	Cutbanks along Bow	50 - 150[c]	
Sediment Output	Bow below Bassano	101 - 346[a]	101 - 346
Sedimentation Rate	Bassano Dam		351 - 698

[a] as in Table 8-5; [b] estimated as in Table 8-6; [c] estimated by extrapolation from Red Deer Badlands (Campbell 1970, 1973, 1974).

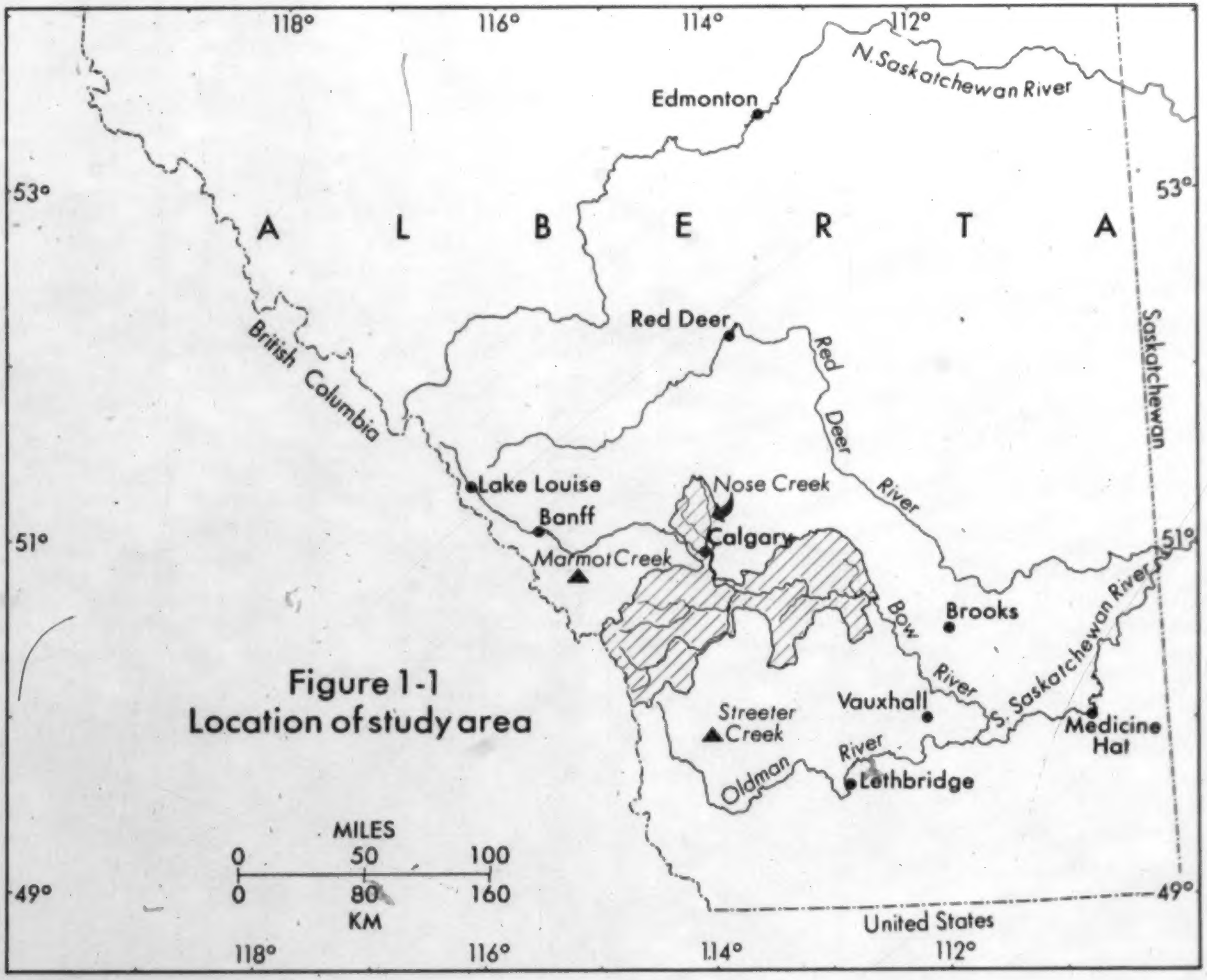

118°
116°
114°
112°
53°
51°
49°
N. Saskatchewan River
Edmonton
A L B E R T A
Red Deer
Red Deer River
Saskatchewan
British Columbia
Lake Louise
Banff
Marmot Creek
Nose Creek
Calgary
Bow River
Brooks
S. Saskatchewan River
Vauxhall
Medicine Hat
Streeter Creek
Oldman River
Lethbridge
MILES
0
50
100
0
80
160
KM
United States

Figure 1-1
Location of study area

Figure 1-2
Topography of study area

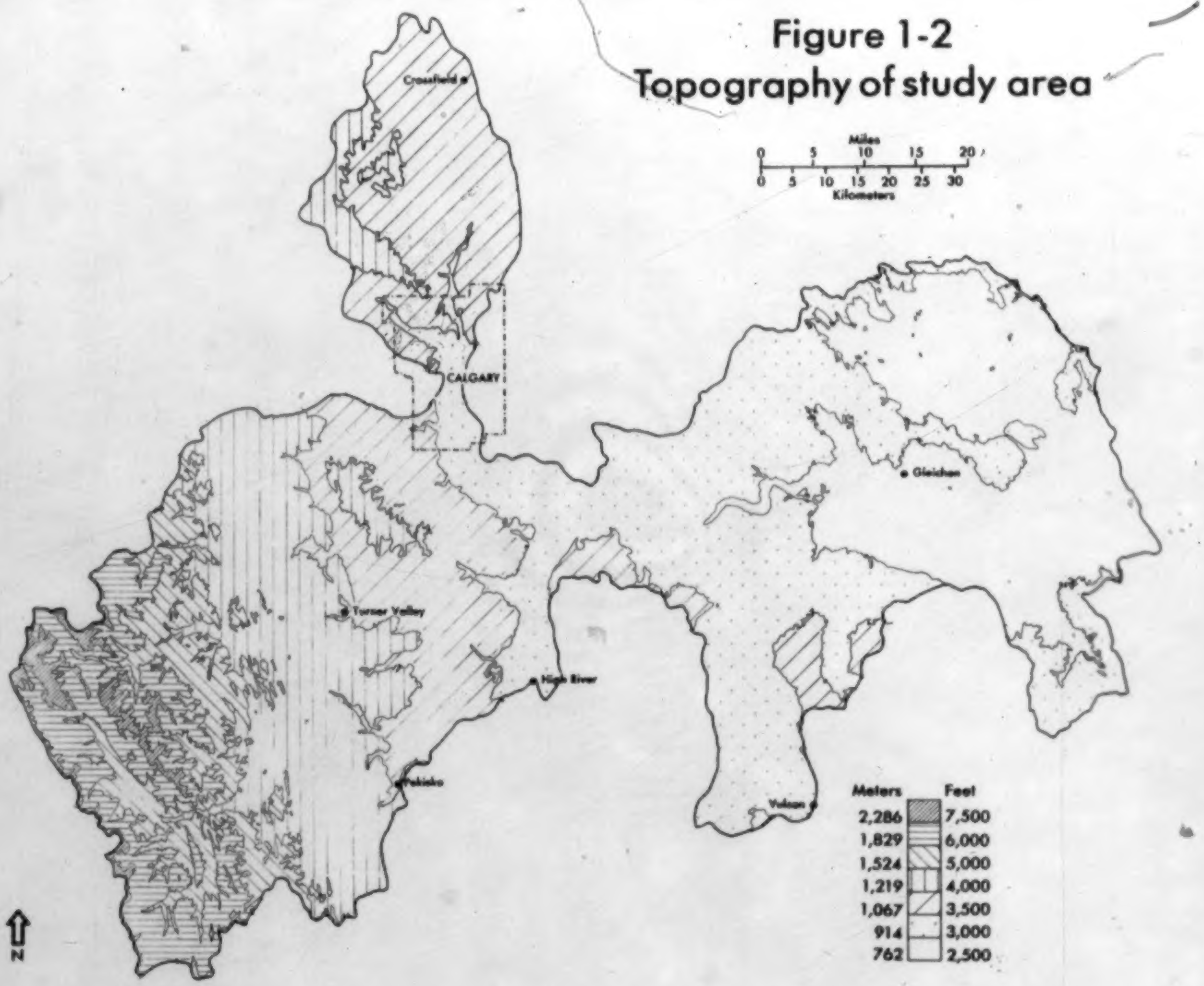
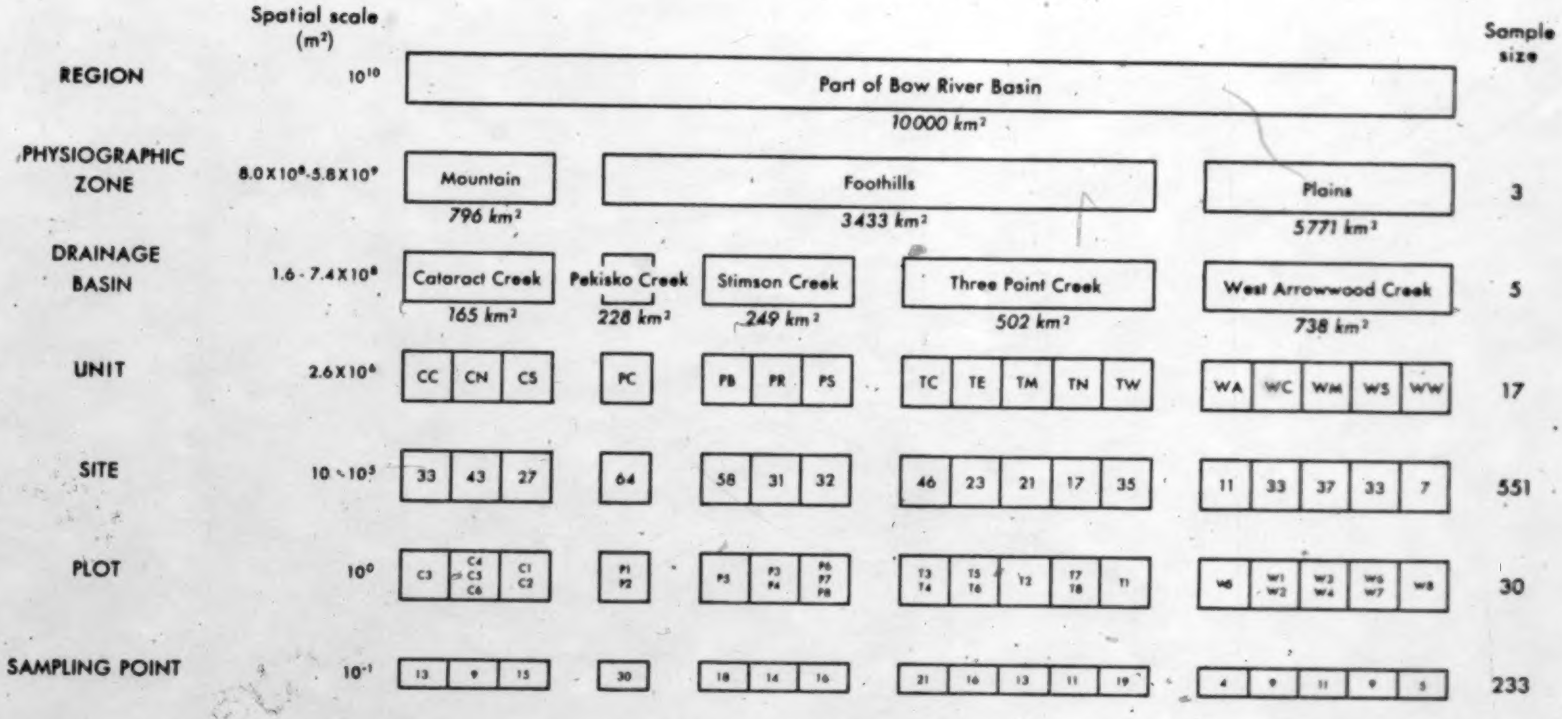

Miles
0 5 10 15 20
0 5 10 15 20 25 30
Kilometers
Crossfield
CALGARY
Gleichen
Turner Valley
High River
Pekisko
Vulcan
Meters
Feet
2,286 7,500
1,829 6,000
1,524 5,000
1,219 4,000
1,067 3,500
914 3,000
762 2,500
N

Figure 1-3

Schematic diagram to show sampling hierarchy


Spatial scale (m²)
Sample size
REGION
10¹⁰
Part of Bow River Basin
10000 km²
PHYSIOGRAPHIC ZONE
8.0X10⁸-5.8X10⁹
Mountain
796 km²
Foothills
3433 km²
Plains
5771 km²
3
DRAINAGE BASIN
1.6 - 7.4X10⁸
Cataract Creek
165 km²
Pekisko Creek
228 km²
Stimson Creek
249 km²
Three Point Creek
502 km²
West Arrowwood Creek
738 km²
5
UNIT
2.6X10⁶
CC CN CS
PC
PB PR PS
TC TE TM TN TW
WA WC WM WS WW
17
SITE
10 - 10⁵
33 43 27
64
58 31 32
46 23 21 17 35
11 33 37 33 7
551
PLOT
10⁰
C3 C4 C5 C6 C1 C2
P1 P2
P5 P3 P4 P6 P7 P8
T3 T4 T5 T6 T2 T7 T8 T1
W5 W1 W2 W3 W4 W6 W7 W8
30
SAMPLING POINT
10⁻¹
13 9 15
30
18 14 16
21 16 13 11 19
4 9 11 9 5
233

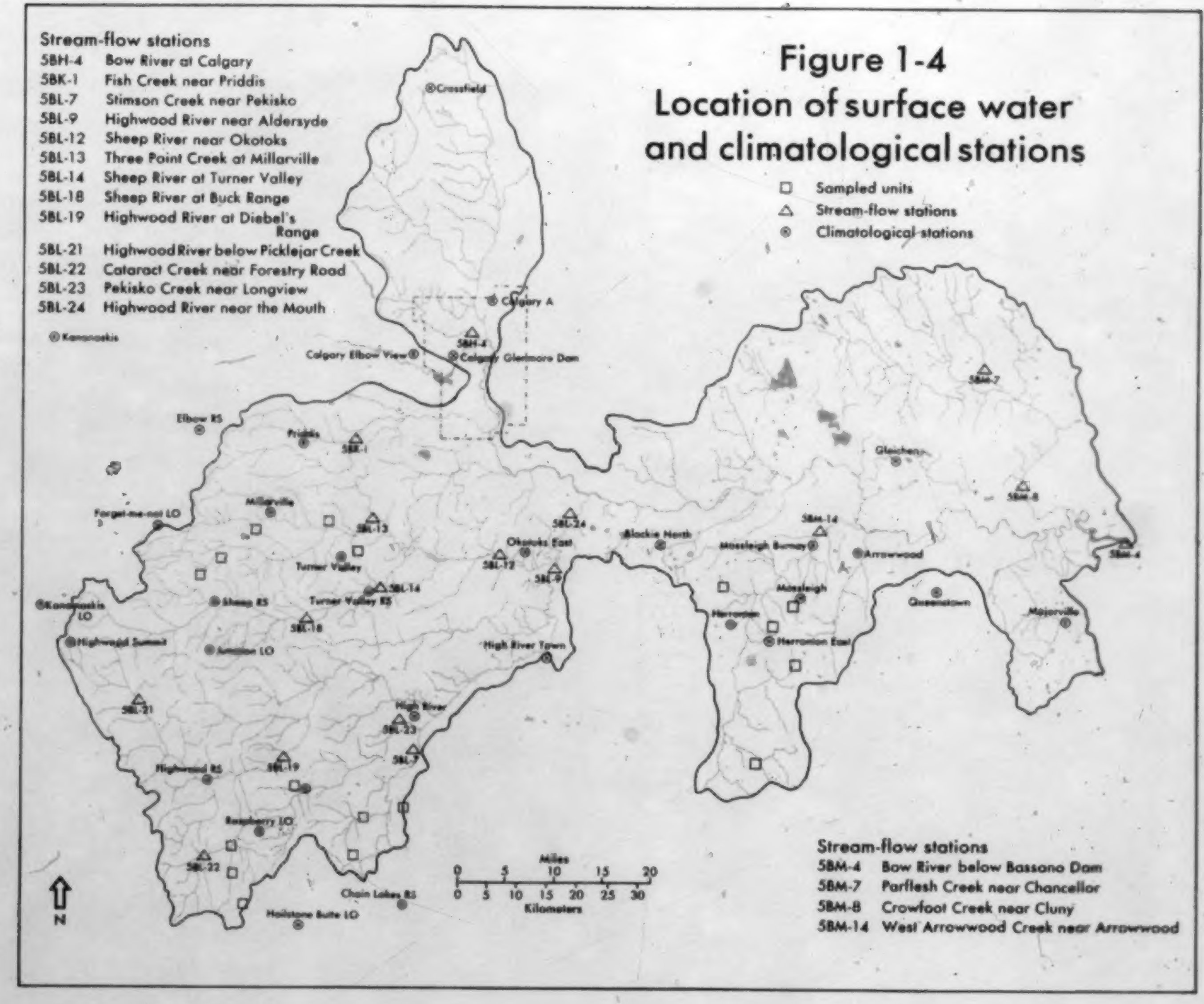


Figure 1-4
Location of surface water and climatological stations

□	Sampled units
△	Stream-flow stations
⊛	Climatological stations

Stream-flow stations

5BH-4	Bow River at Calgary
5BK-1	Fish Creek near Priddis
5BL-7	Stimson Creek near Pekisko
5BL-9	Highwood River near Aldersyde
5BL-12	Sheep River near Okotoks
5BL-13	Three Point Creek at Millarville
5BL-14	Sheep River at Turner Valley
5BL-18	Sheep River at Buck Range
5BL-19	Highwood River at Diebel's Range
5BL-21	Highwood River below Picklejar Creek
5BL-22	Cataract Creek near Forestry Road
5BL-23	Pekisko Creek near Longview
5BL-24	Highwood River near the Mouth

Stream-flow stations

5BM-4	Bow River below Bassano Dam
5BM-7	Parflesh Creek near Chancellor
5BM-8	Crowfoot Creek near Cluny
5BM-14	West Arrowwood Creek near Arrowwood

Kananaskis
Crossfield
Calgary A
5BH-4
Calgary Elbow View
Calgary Glenmore Dam
Elbow RS
Priddis
5BK-1
Millarville
Forget-me-not LO
5BL-13
Turner Valley
5BL-14
Turner Valley RS
Sheep RS
Kananaskis LO
Highwood Summit
Jumpingpound LO
5BL-18
5BL-24
Okotoks East
5BL-12
5BL-9
High River Town
5BL-21
High River
5BL-23
5BL-7
Highwood RS
5BL-19
Raspberry LO
5BL-22
Chain Lakes RS
Hailstone Butte LO
Miles
0 5 10 15 20
0 5 10 15 20 25 30
Kilometers
N
Blackie North
Mossleigh Burnay
5BM-14
Arrowwood
Mossleigh
Herronton
Herronton East
Queenstown
Gleichen
5BM-7
5BM-8
5BM-4
Majorville

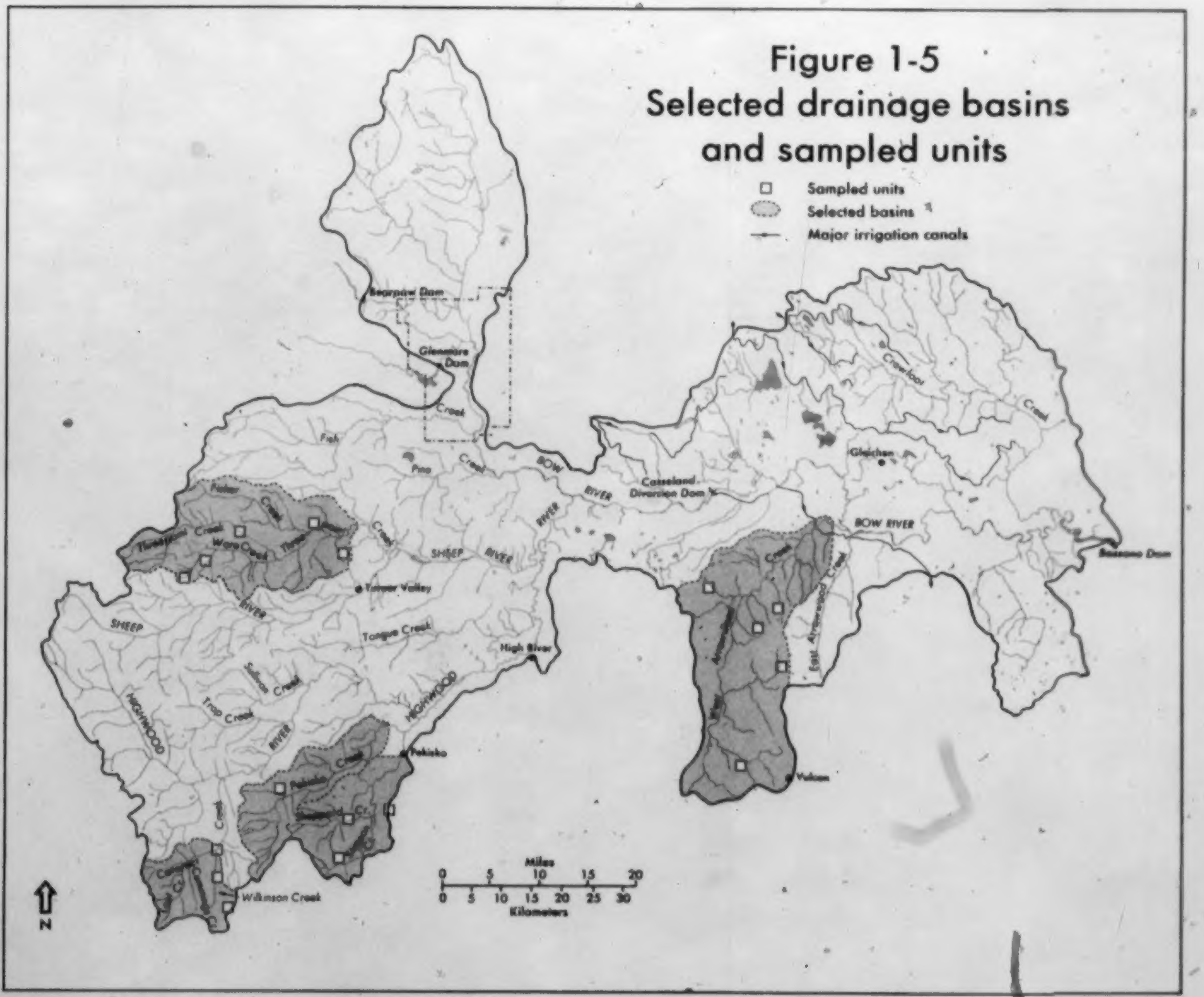


Figure 1-5
Selected drainage basins
and sampled units

□ Sampled units
Selected basins
Major irrigation canals
Bearspaw Dam
Glenmore Dam
Creek
Fish
Pine
Creek
BOW
RIVER
RIVER
Carseland Diversion Dam
Crowfoot
Creek
Gleichen
BOW RIVER
Bassano Dam
Fisher
Creek
Threepoint Creek
Ware Creek
Three
Creek
SHEEP
RIVER
Turner Valley
RIVER
SHEEP
Tongue Creek
High River
Sullivan Creek
Trap Creek
HIGHWOOD
HIGHWOOD
RIVER
Pekisko
Creek
Pekisko
Cr.
Creek
Cr.
Cr.
Wilkinson Creek
Creek
East Arrowwood Creek
Arrowwood
Vulcan
Miles
0 5 10 15 20
0 5 10 15 20 25 30
Kilometers
N

Bedrock Geology

TERTIARY

PALEOCENE

Tp	**PORCUPINE HILLS FORMATION**: pale grey, thick-bedded, cherty, calcareous sandstone; pale grey calcareous mudstone; nonmarine

TERTIARY AND CRETACEOUS

PALEOCENE AND UPPER CRETACEOUS

TKp	**PASKAPOO FORMATION**: grey to greenish grey, thick-bedded, calcareous, cherty sandstone; grey and green siltstone and mudstone; minor conglomerate, thin limestone, coal and tuff beds. **Scollard Member (Ksc)**: grey feldspathic sandstone, dark grey bentonitic mudstone; thick coal beds, nonmarine
TKb	**BRAZEAU FORMATION**: greenish grey, thick-bedded, chloritic and feldspathic sandstone and blocky grey mudstone; some tuff and thin coal beds; nonmarine

CRETACEOUS

Ka	**ALBERTA GROUP**: dark grey, fissile, silty shale, some thin-bedded, fine- to medium-grained, cherty sandstone (Blackstone Formation)—thick-bedded, well-sorted, quartzose sandstone, dark grey shale and carbonaceous shale; siltstone and thin coal beds (Cardium Formation)—dark grey fissile shale and siltstone, thin-bedded, fine-grained, glauconitic sandstone, thin beds of concretionary ironstone (Wapiabi Formation)—Note: north of Athabasca River areas designated as **Ka** include Smoky Group, Dunvegan and Shaftesbury Formations (stratigraphic equivalents of Alberta Group)

UPPER CRETACEOUS

Khc	**HORSESHOE CANYON FORMATION**: grey, feldspathic, clayey sandstone; grey bentonitic mudstone and carbonaceous shale; concretionary ironstone beds, scattered coal and bentonite beds of variable thickness, minor limestone beds; mainly nonmarine
Kbp	**BEARPAW FORMATION**: dark grey blocky shale and silty shale; greenish glauconitic and grey clayey sandstone; thin concretionary ironstone and bentonite beds; marine

MESOZOIC

Mz	**LOWER CRETACEOUS, JURASSIC AND TRIASSIC**: dark grey to black siltstone, dolomitic siltstone and limestone, silty dolomite, limestone, breccia and gypsum (Triassic)—dark grey to black fissile shale and siltstone, black cherty and phosphatic dolomite and limestone; green glauconitic shale and sandstone (Jurassic)—thick-bedded, fine- to coarse-grained, cherty sandstone interbedded with dark grey shale, siltstone and coal (Nikanassin and Kootenay Formations)—grey, siliceous, calcareous sandstone, green chloritic and feldspathic sandstone, dark grey carbonaceous and calcareous shale, grey, green, and red shale and silty shale, some conglomerate; coal in central and northern Foothills; trachytic tuff, agglomerate in southern Foothills (Blairmore Group)

PALEOZOIC

Pzu	**UPPER PALEOZOIC**: grey argillaceous limestone and dolomite, in part cherty and stromatoporoidal, in part coarsely biostromal; black nodular and calcareous shale; grey to brown aphanitic to finely crystalline limestone, dolomite-mottled limestone, and dolomite; black bituminous shale (Upper Devonian)—dark grey fissile shale, siltstone, argillaceous limestone and cherty limestone; medium- to coarse-grained crinoidal limestone, cherty and dolomitic limestone; dolomite, cherty dolomite, anhydrite, red shale and sandstone (Mississippian)—thin- and thick-bedded quartzose sandstone, phosphatic quartzose siltstone, silty and cherty dolomite, chert and cherty carbonate (Pennsylvanian-Permian)

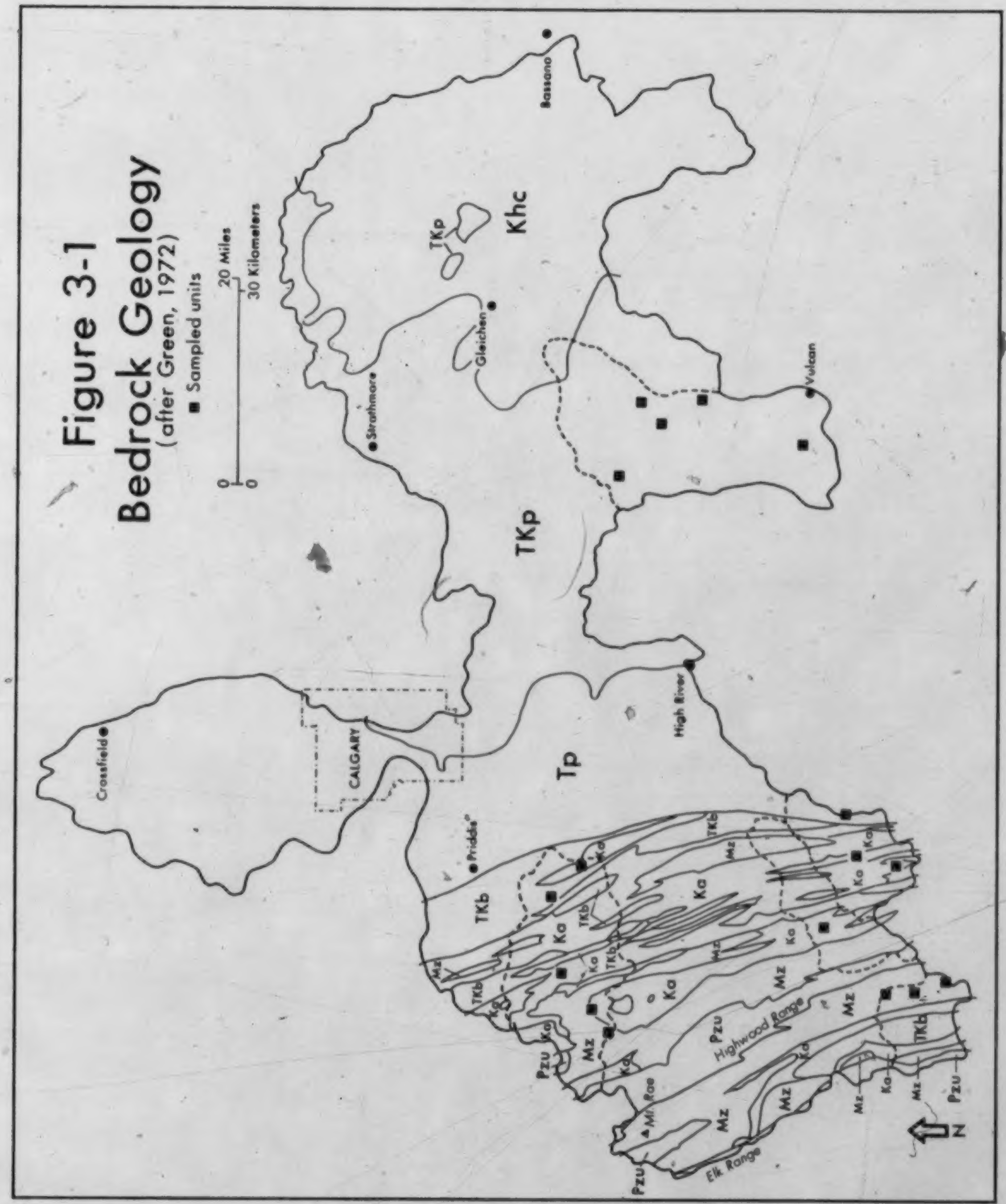

■ Sampled units
0
20 Miles
0
30 Kilometers
Crossfield
CALGARY
Strathmore
Gleichen
Bassano
Vulcan
High River
Priddis
TKp
Khc
Tp
TKb
Ka
Mz
Pzu
Highwood Range
Mt. Rae
Elk Range
N

Figure 3-1
Bedrock Geology
(after Green, 1972)

Figure 3-2a

CataractCreek:Soil distribution by parent material

Source: Laycock (1957b)

A. Bare rock and rocky alpine soils
B. Residual soils
C. Colluvial soils
D. Glacial soils, other than glacio-fluvial
E. Alluvial and glacio-fluvial soils

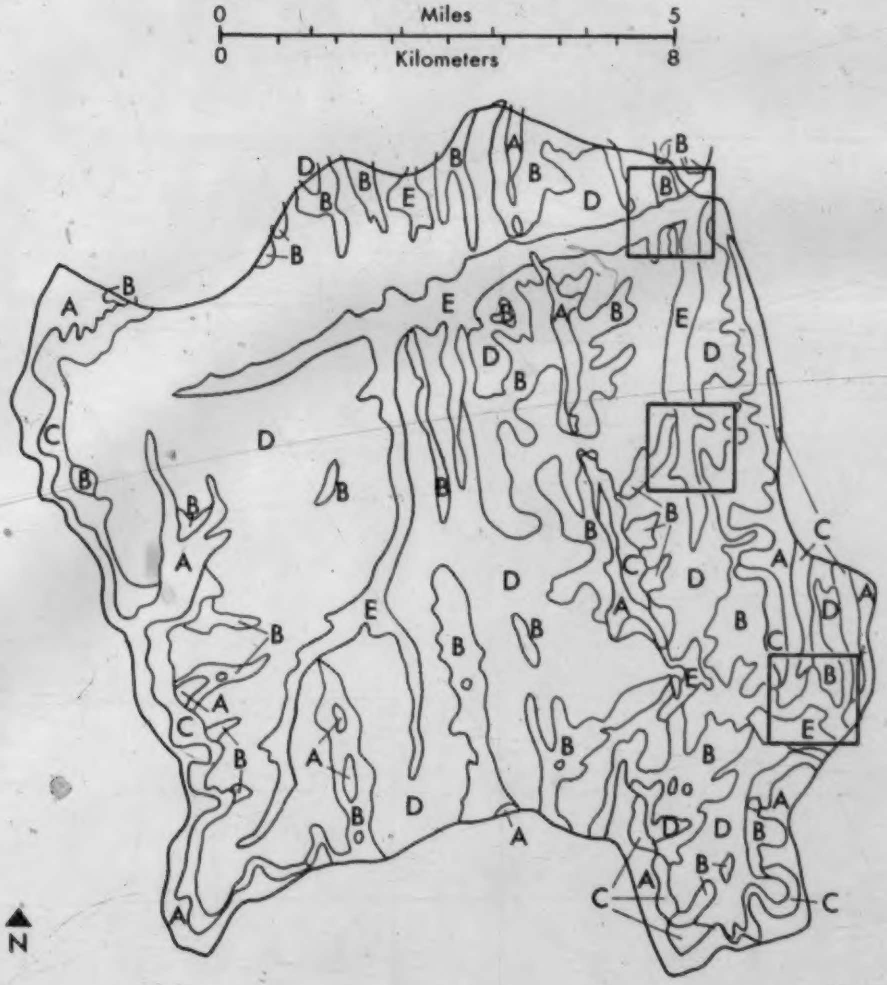

0
Miles
5
0
Kilometers
8
A
B
C
D
E
N

Figure 3-2b
Pekisko and Stimson Creeks: Soil distribution by parent material

Source: Wyatt et al (1942) Alberta Soil Survey (unpublished) revised (1960)

1. Sorted residual
2. Glacial
4. Gravelly outwash
5. Alluvial Resorted

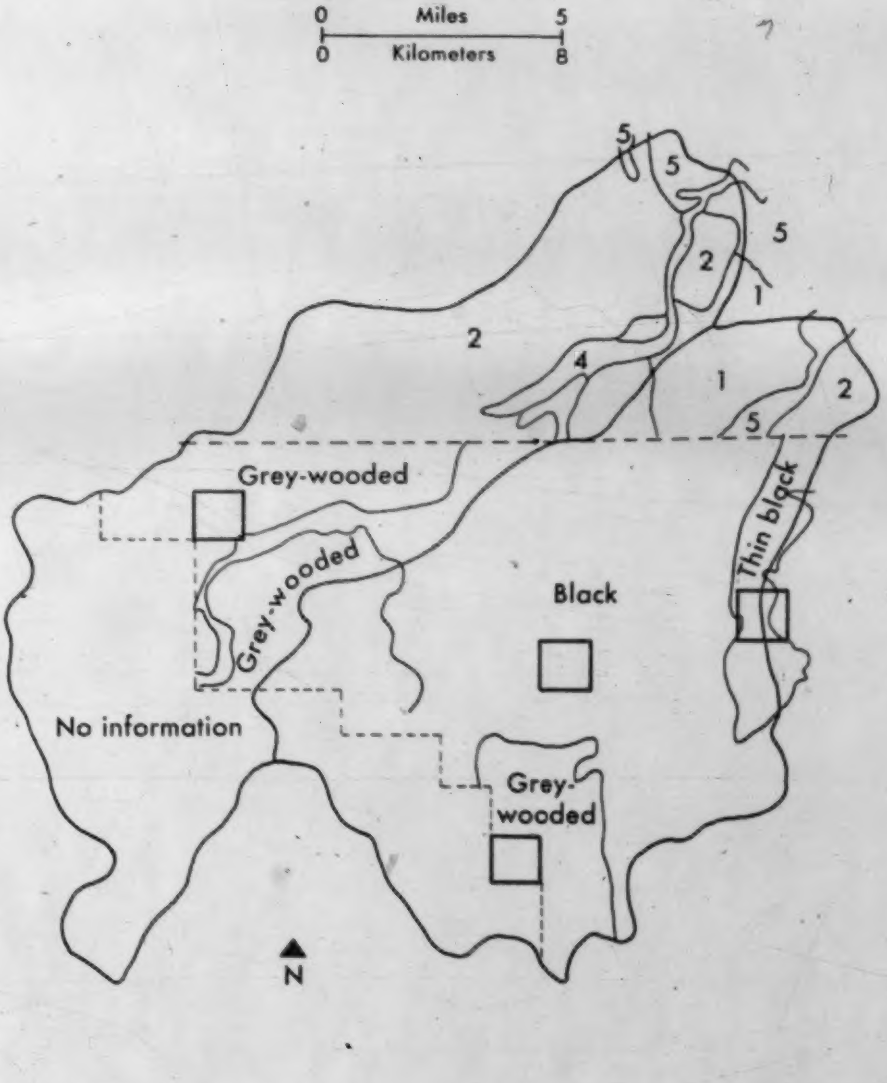

0
Miles
5
0
Kilometers
8
5
5
5
2
1
2
4
1
2
5
Grey-wooded
Thin black
Grey-wooded
Black
No information
Grey-wooded
N

Figure 3-2c

Three Point Creek: Soil distribution by parent material

Source: Laycock (1957b); Wyatt et al (1942) revised (1960)

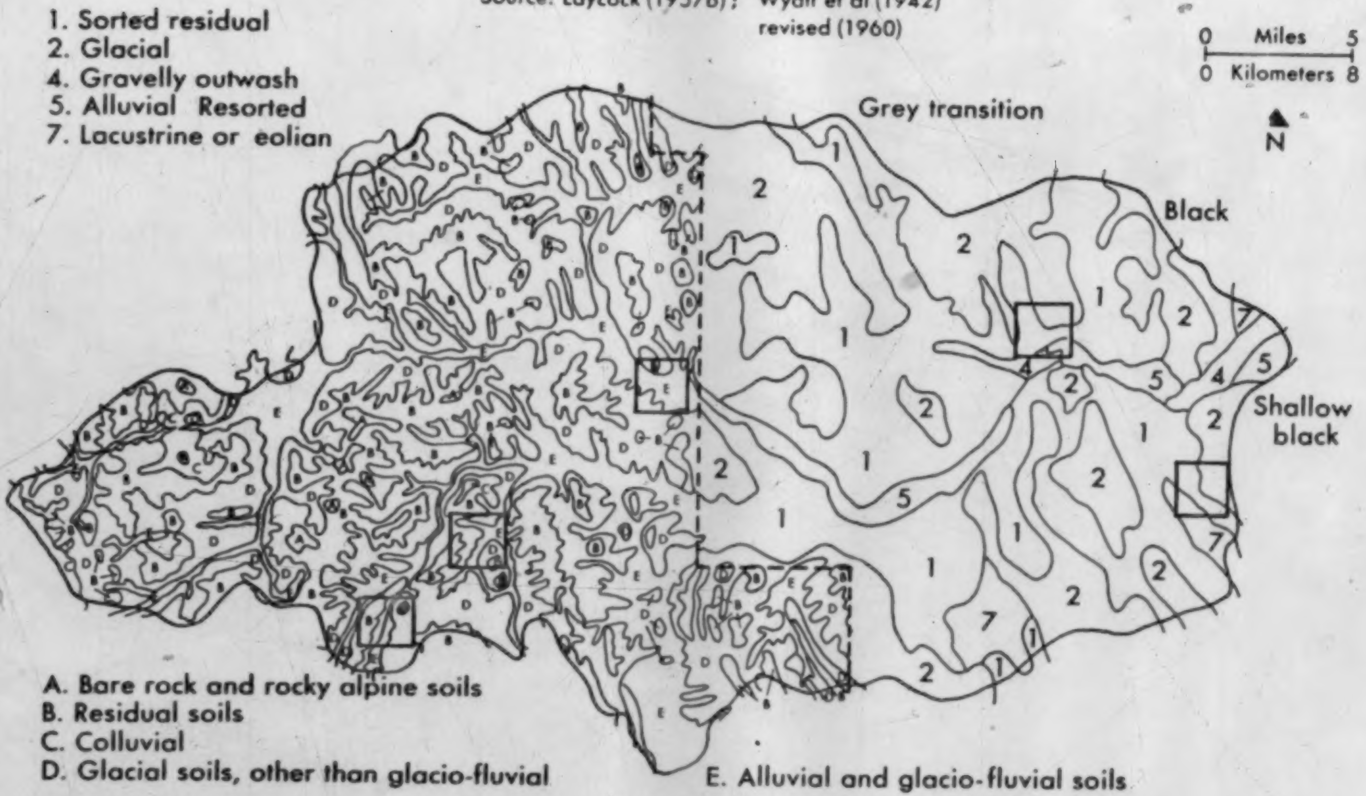

1. Sorted residual
2. Glacial
4. Gravelly outwash
5. Alluvial Resorted
7. Lacustrine or eolian
0 Miles 5
0 Kilometers 8
N
Grey transition
Black
Shallow black
A. Bare rock and rocky alpine soils
B. Residual soils
C. Colluvial
D. Glacial soils, other than glacio-fluvial
E. Alluvial and glacio-fluvial soils

Figure 3-2d
West Arrowwood Creek:
Soil distribution by parent material
Wyatt et al (1942)
revised (1960)

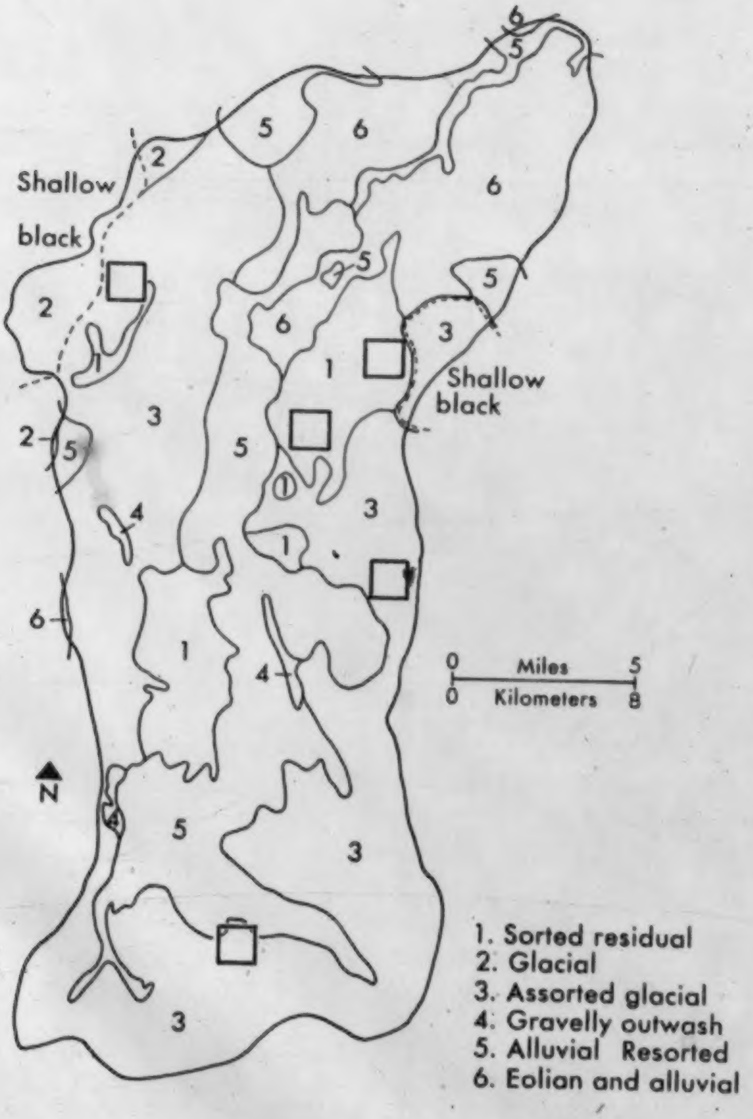

Shallow black
Shallow black
1
2
3
4
5
6
0 Miles 5
0 Kilometers 8
N
1. Sorted residual
2. Glacial
3. Assorted glacial
4. Gravelly outwash
5. Alluvial Resorted
6. Eolian and alluvial

Figure 3-3

Mean monthly temperature of three selected stations

Data Source: Atmospheric Environment Service, Environment Canada (1973)

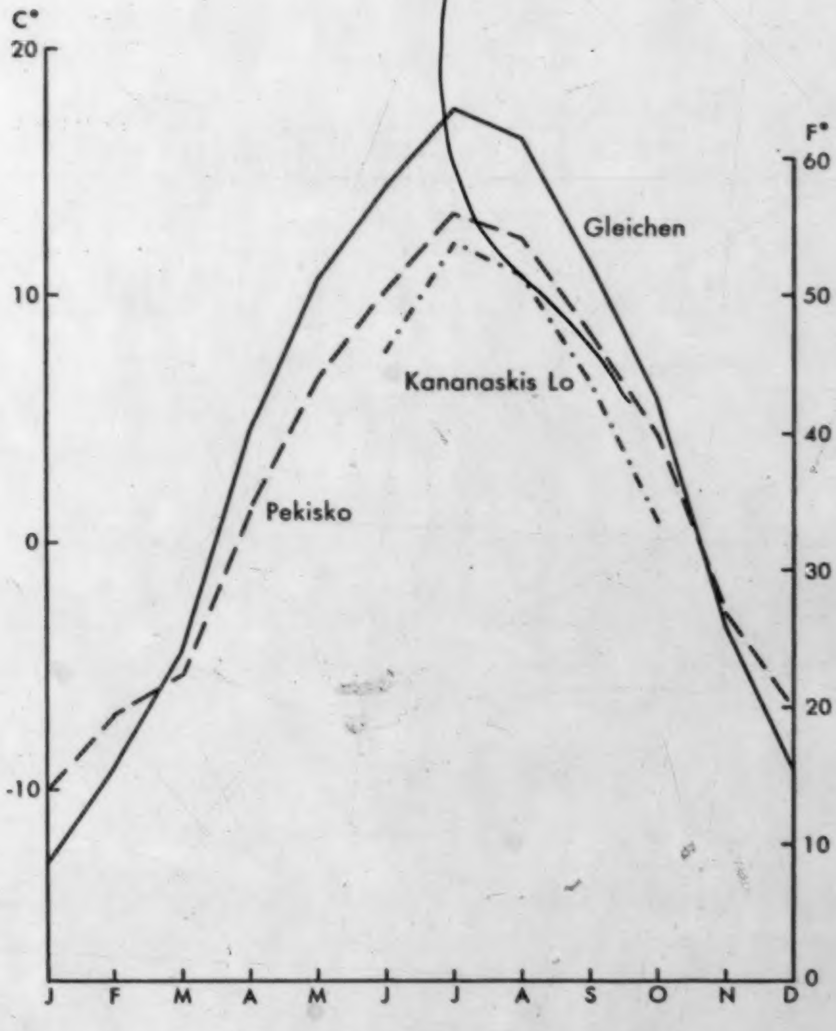
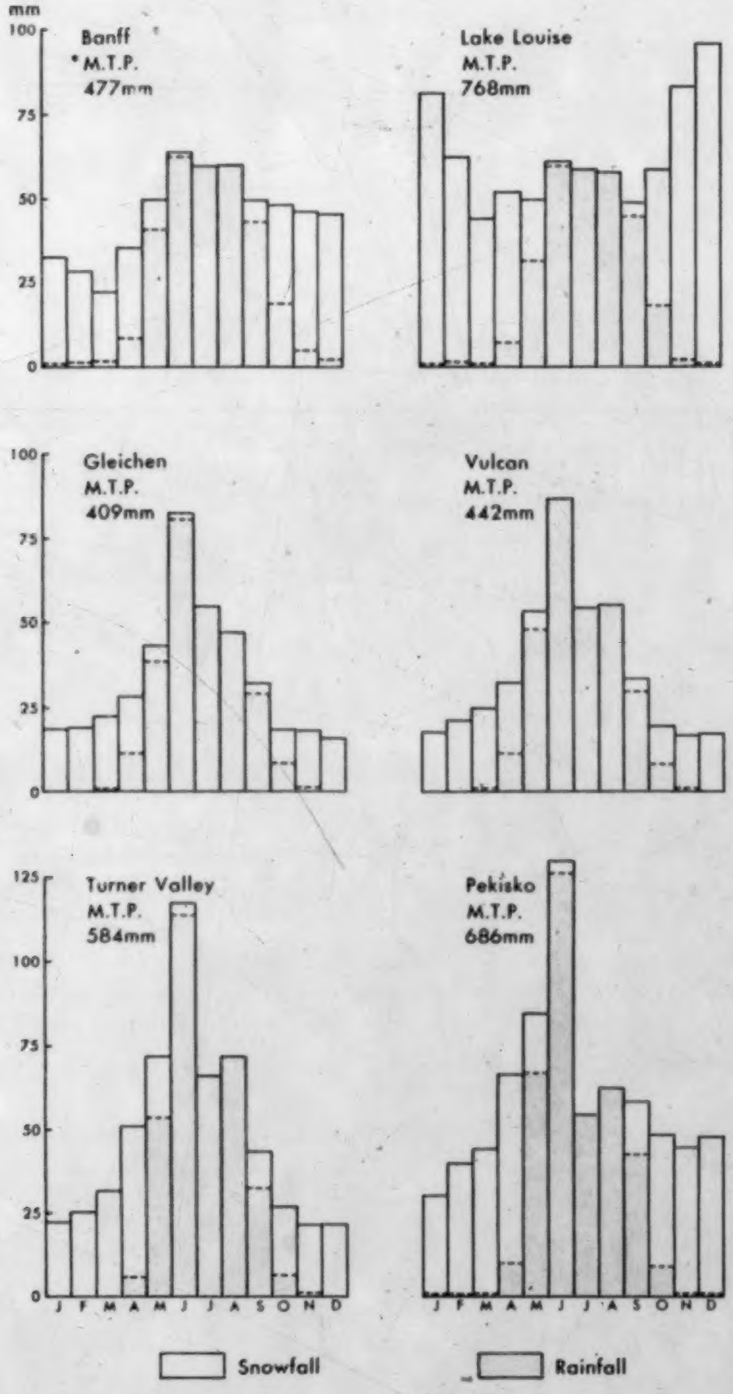


Figure 3-4

Mean monthly precipitation and rainfall of six selected stations

Data Source: Atmospheric Environment Service, Environment Canada, (1973)



* Mean Total Precipitation

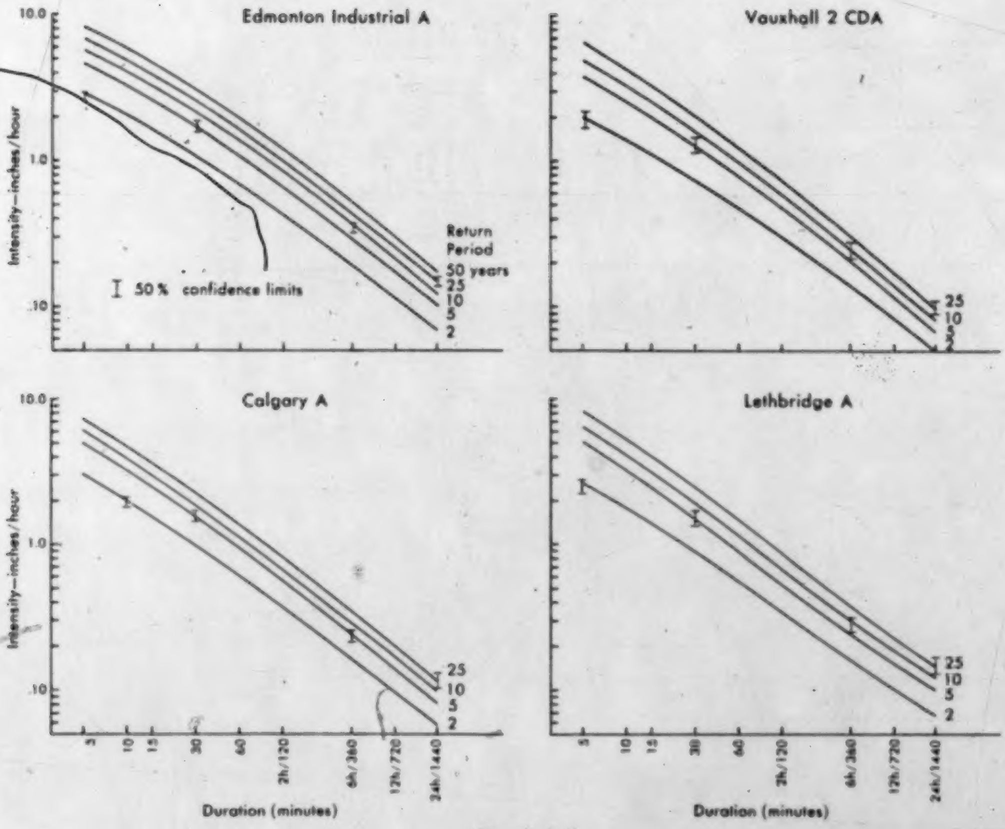


Figure 3-5

Short duration rainfall intensity—frequency curves of four selected stations

Data Source: Atmospheric Environment Service, Environment Canada, Unpublished Charts

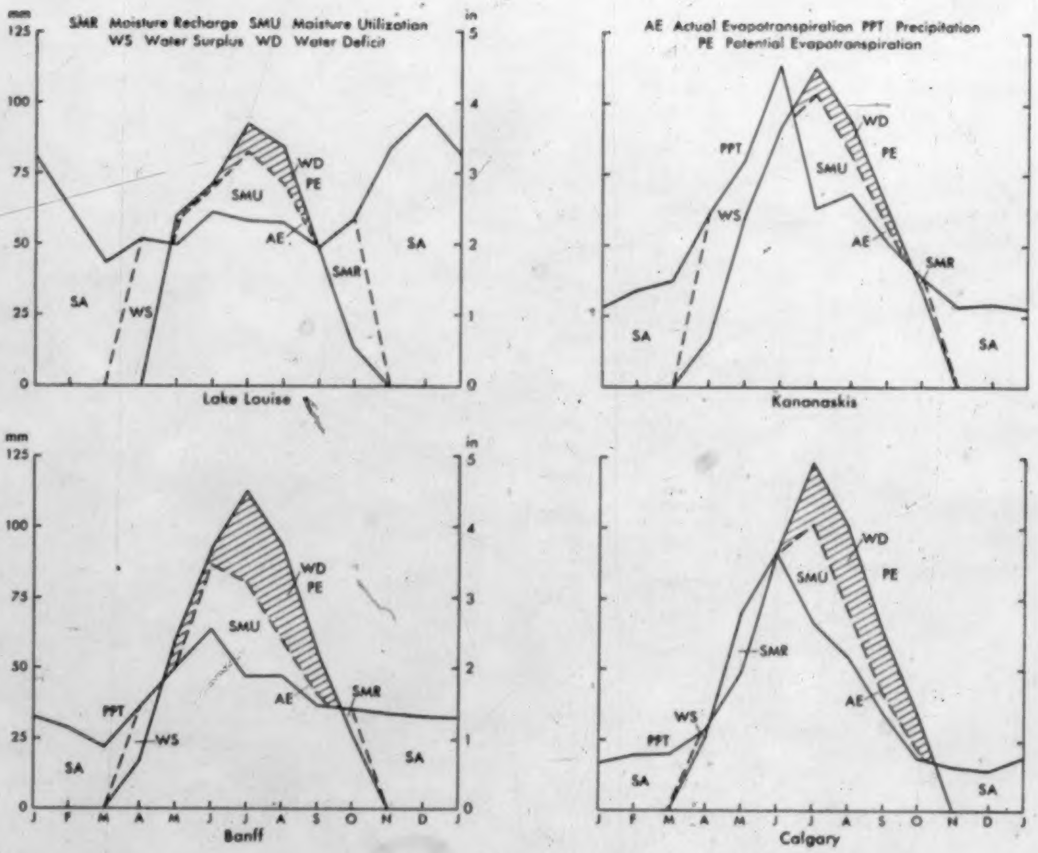


Figure 3-6

Moisture budget for eight selected stations

Data Source: Atmospheric Environment Service, Environment Canada (1973).
Compilation Procedure after Thornthwaite and Mather (1957)

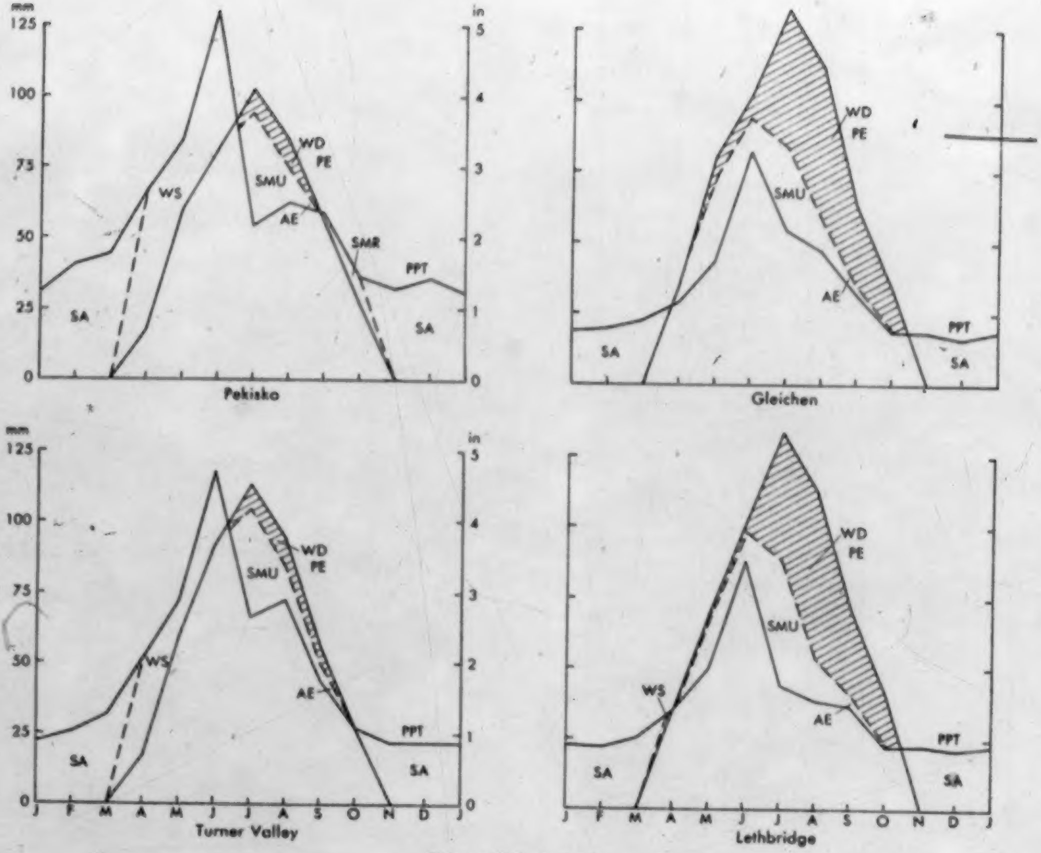


Figure 3-6 (cont.)

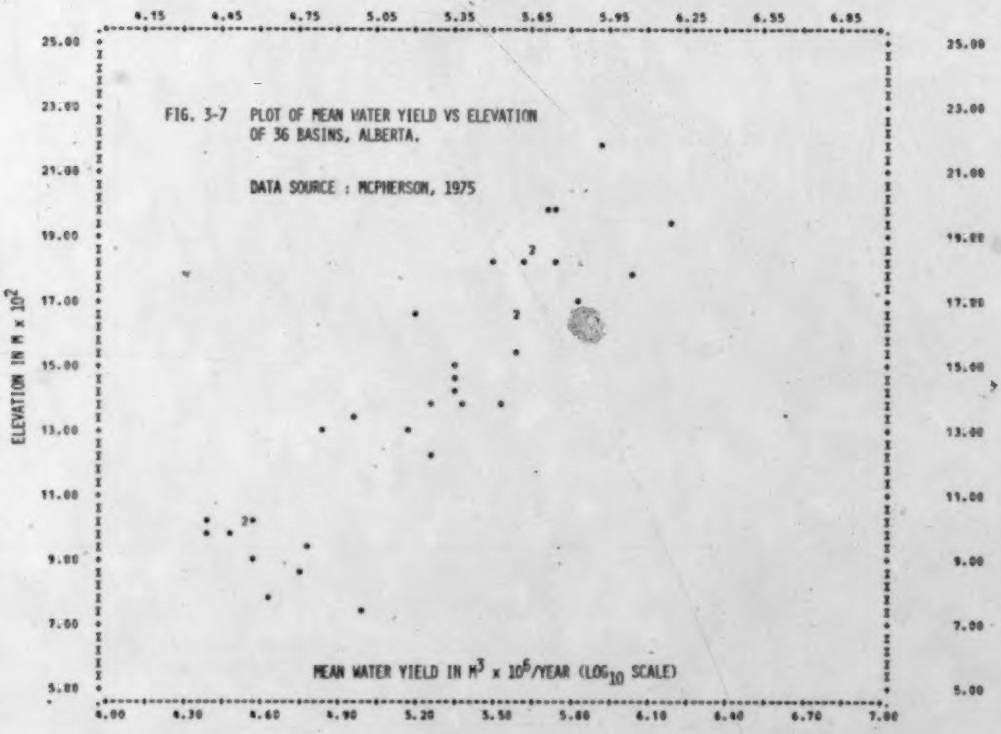
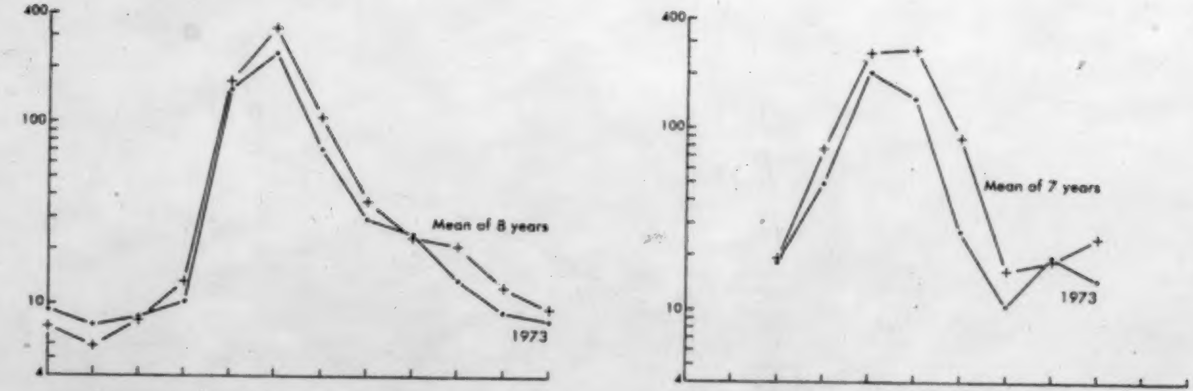


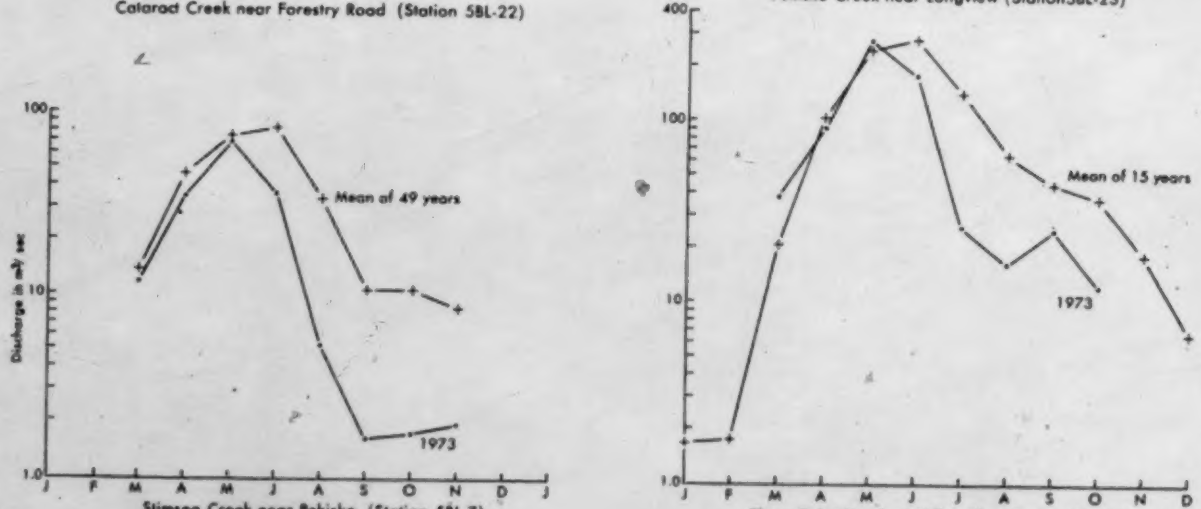
FIG. 3-7 PLOT OF MEAN WATER YIELD VS ELEVATION OF 36 BASINS, ALBERTA.

DATA SOURCE : MCPHERSON, 1975



Cataract Creek near Forestry Road (Station 5BL-22)

Pekisko Creek near Longview (Station 5BL-23)



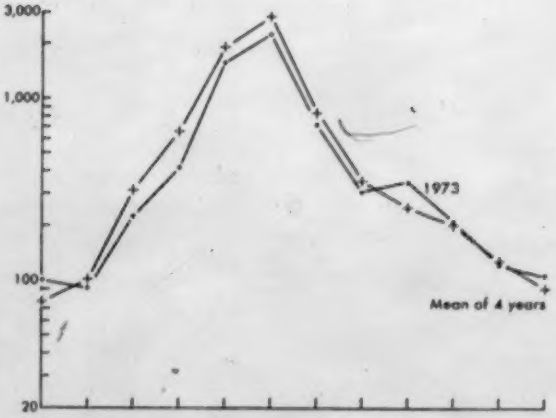
Stimson Creek near Pekisko (Station 5BL-7)

Three Point Creek at Millarville (Station 5BL-13)

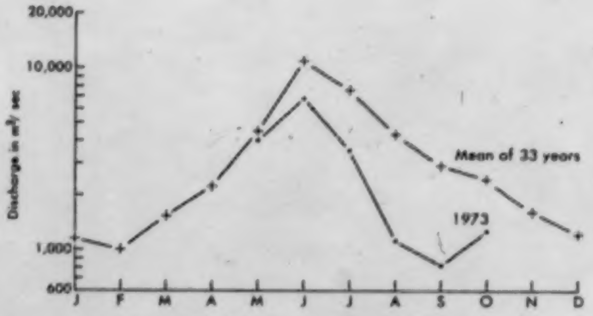
Figure 3-8

Annual hydrograph for seven selected stations

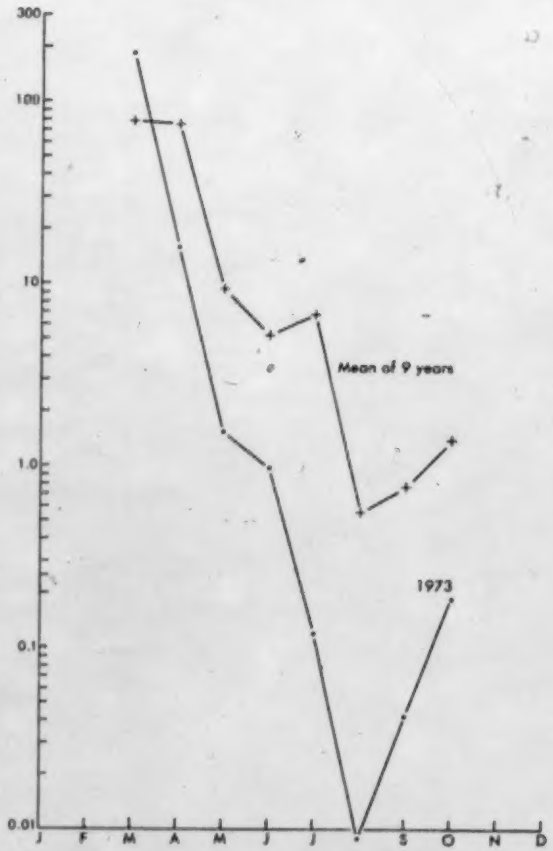
Data Source: Water Survey of Canada, Environment Canada, (1974)



Highwood River near the mouth (Station 5BL-24)



Bow River below Bassano Dam (Station 5BM-4)



West Arrowwood Creek at Arrowwood (Station 5BM-14)

Figure 3-8 (cont.)

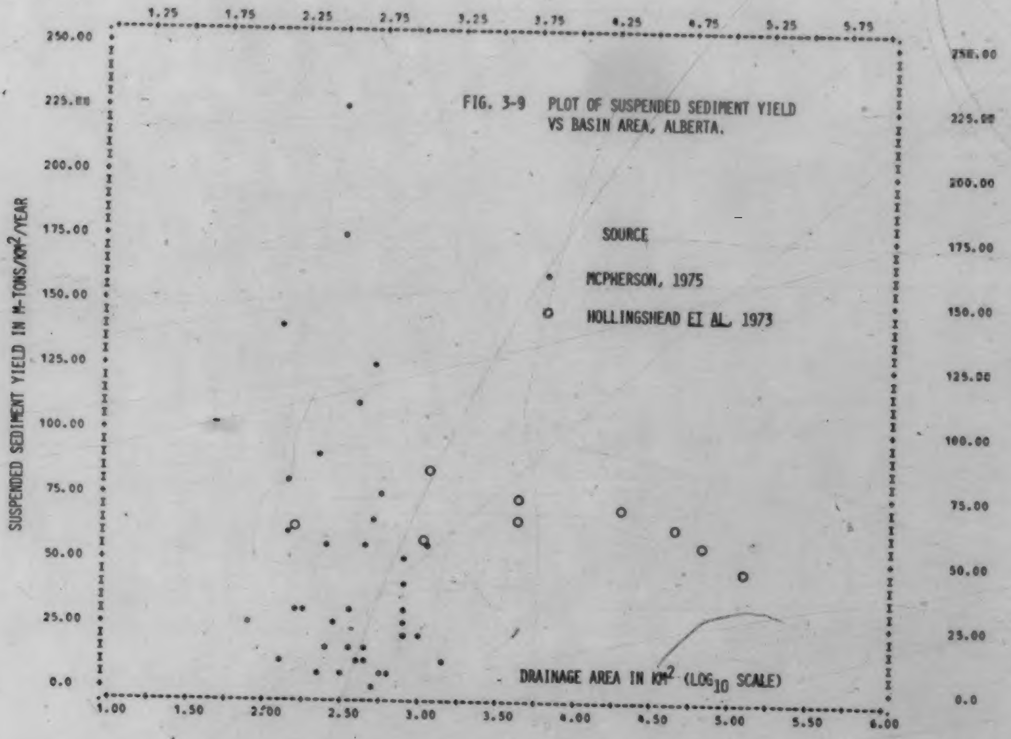


FIG. 3-9 PLOT OF SUSPENDED SEDIMENT YIELD VS BASIN AREA, ALBERTA.

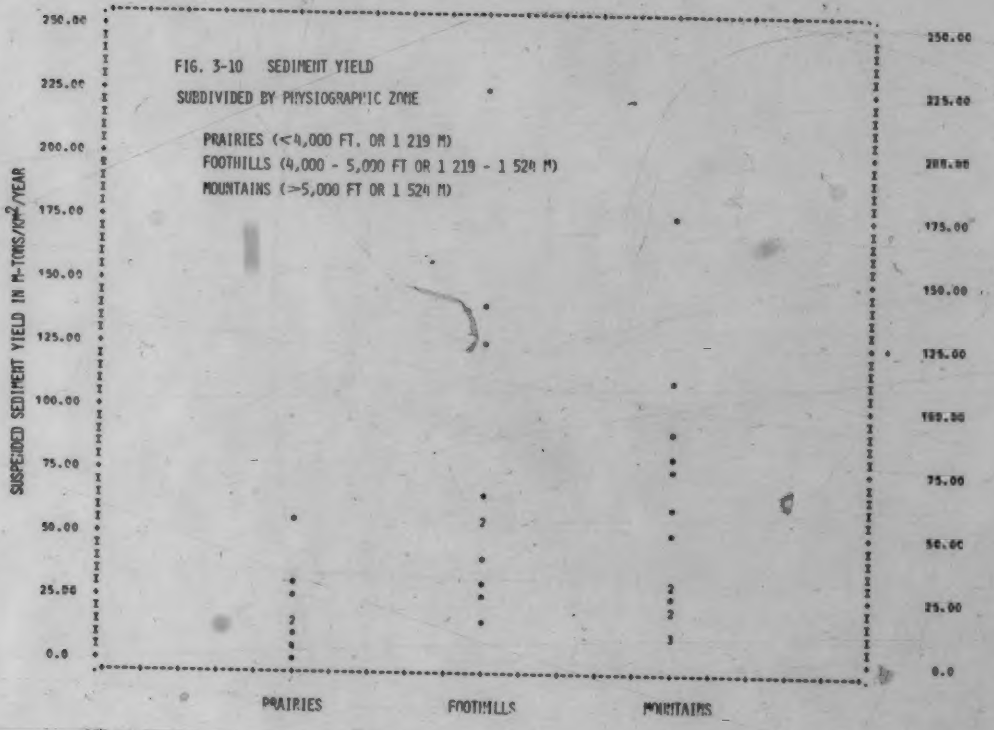


FIG. 3-10 SEDIMENT YIELD

SUBDIVIDED BY PHYSIOGRAPHIC ZONE

PRAIRIES (<4,000 FT. OR 1 219 M)

FOOTHILLS (4,000 - 5,000 FT OR 1 219 - 1 524 M)

MOUNTAINS (>5,000 FT OR 1 524 M)

LEGEND

ↄ Shallow Slumps

ↄ Gully Heads

^ Incipient Gullying

↣ Terrace Scarps

⊙ Sampling Sites

▼ Plot Sites

▨ Permanent Structure

⊟ Sloughs and Lakes

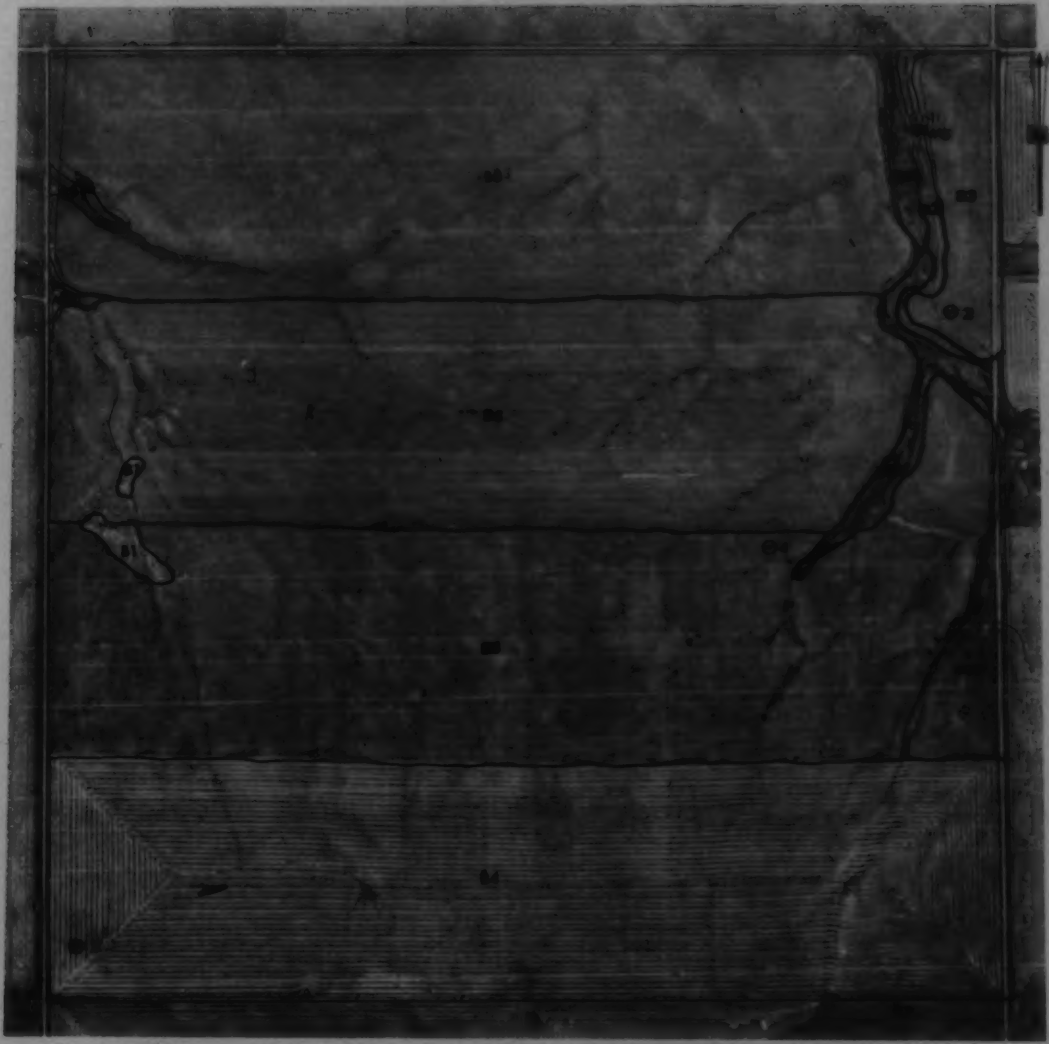


Figure 3-11

Andrews Section, West Arrowwood Creek

(Sect. 9-17-25-W4)

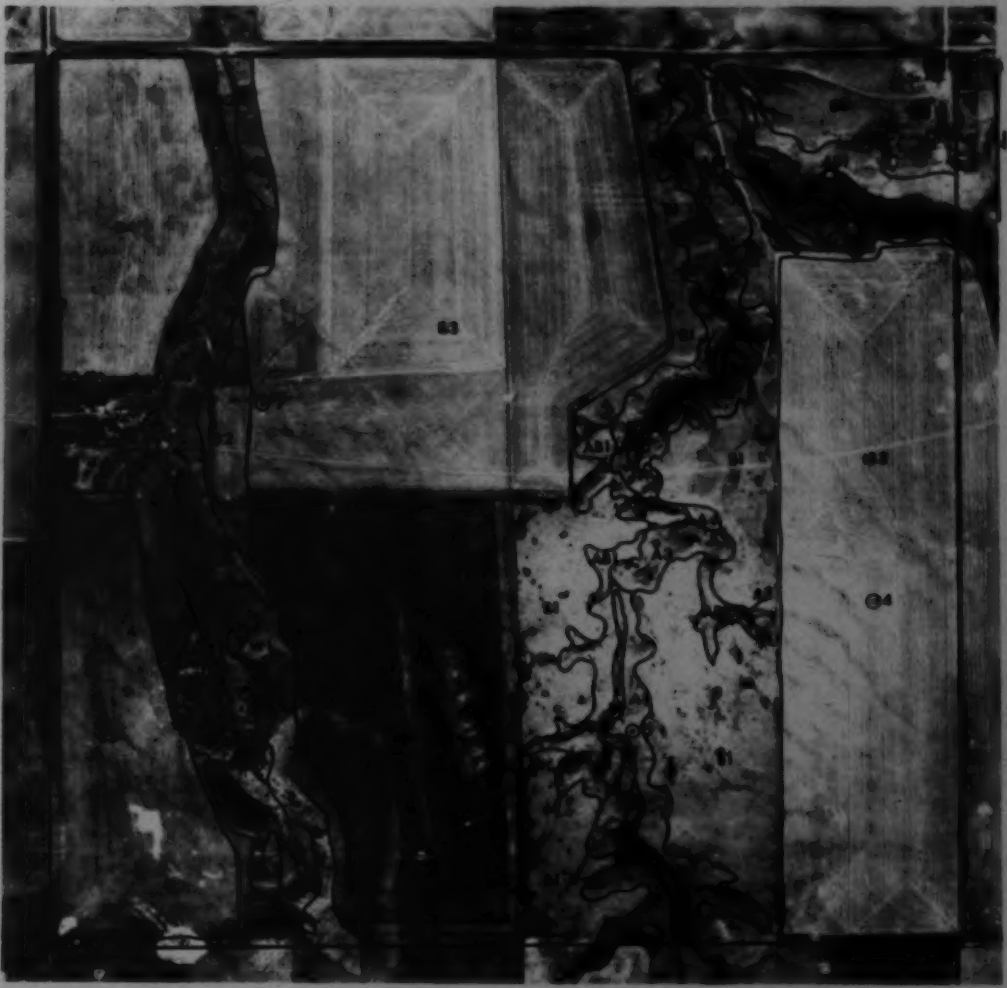


Figure 3-12

Campbell Section, West Arrowwood Creek

(Sect. 32-19-24-W4)

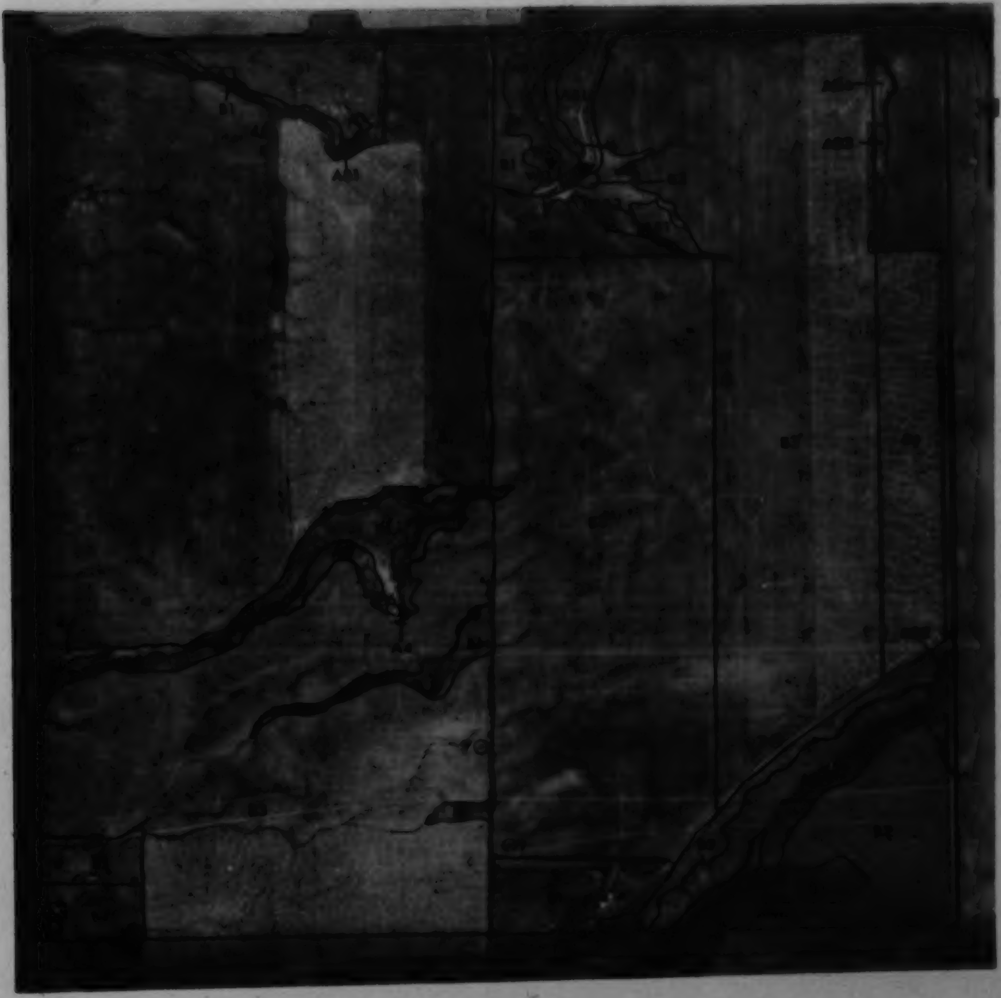


Figure 3-13

Merkel Section, West Arrowwood Creek

(Sect. 24-19-25-W4)

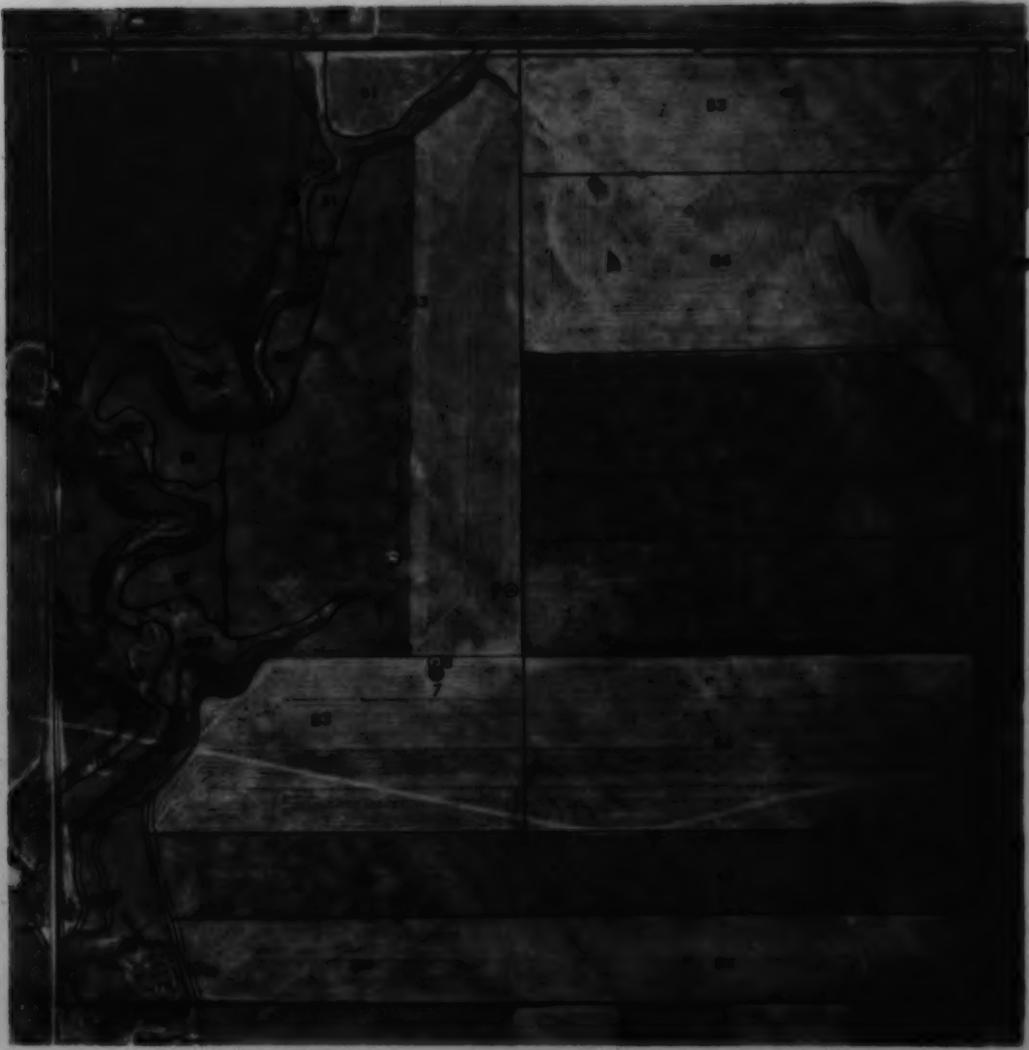


Figure 3-14

Steiner Section, West Arrowood Creek

(Sect. 31-18-24-W4)

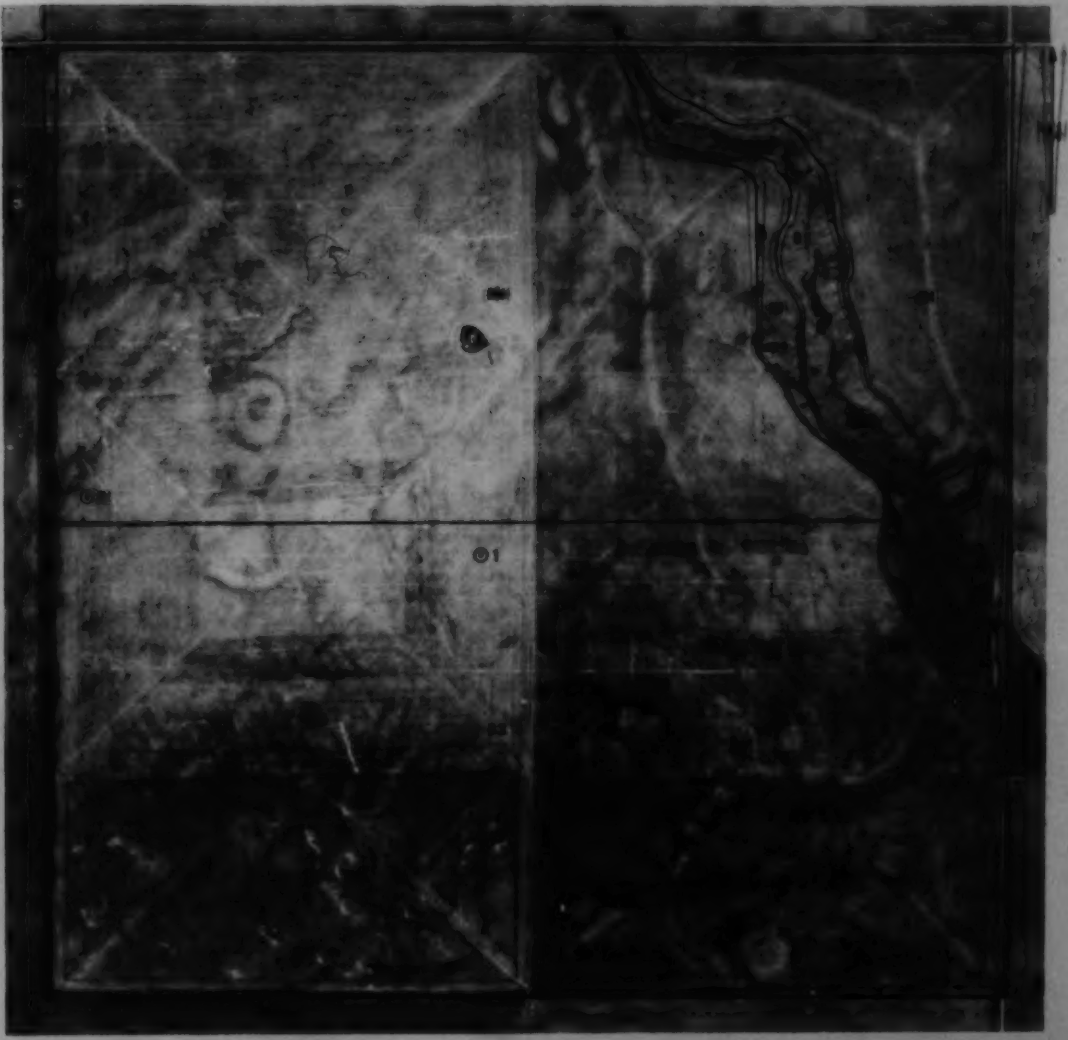


Figure 3-15

Weber Section, West Arrowwood Creek

(Sect. 7-20-25-W4)

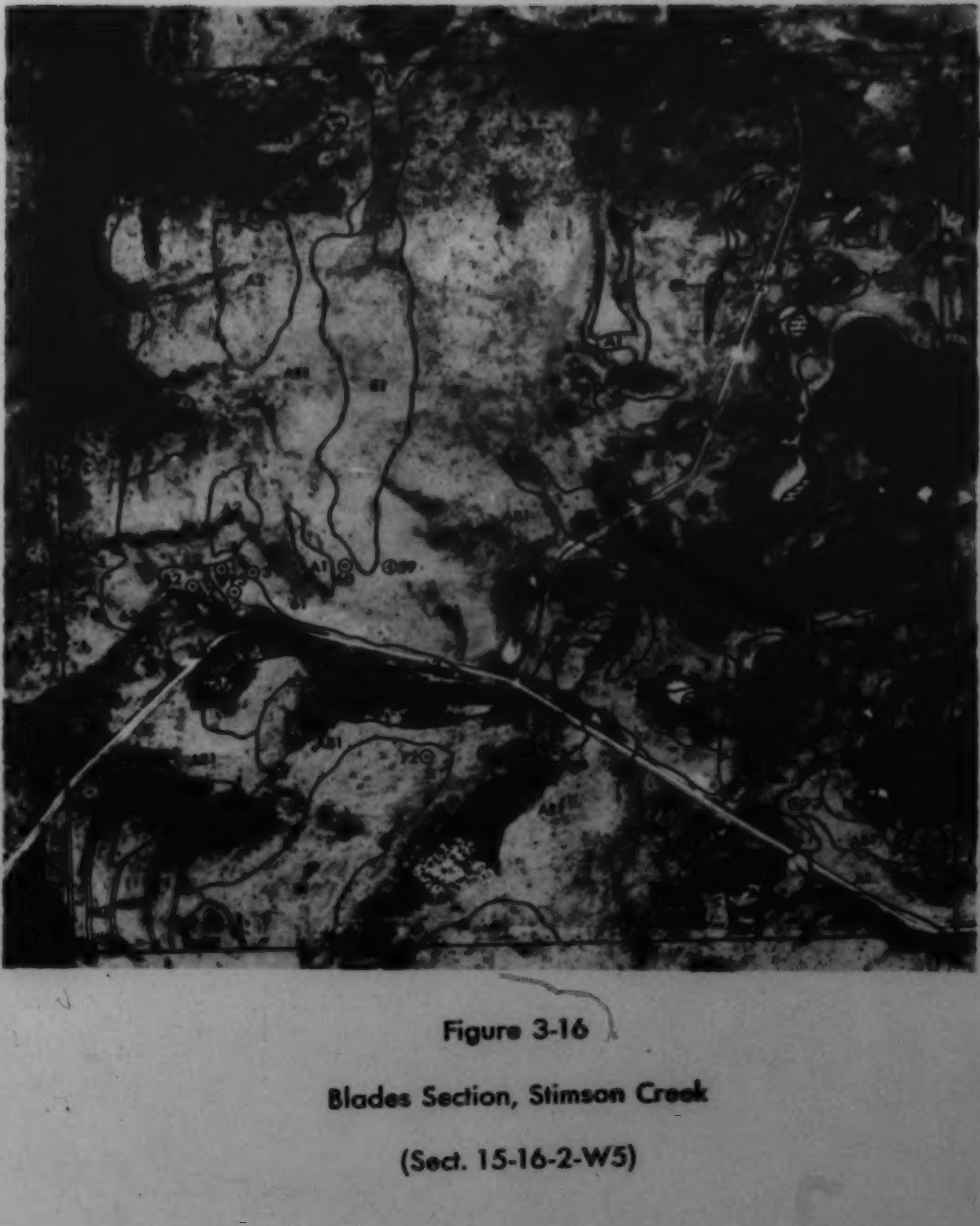

A2
AB1
B1
A1
A1
99
AB1
AB1
AB1
72
AB1

Figure 3-16

Blades Section, Stimson Creek

(Sect. 15-16-2-W5)

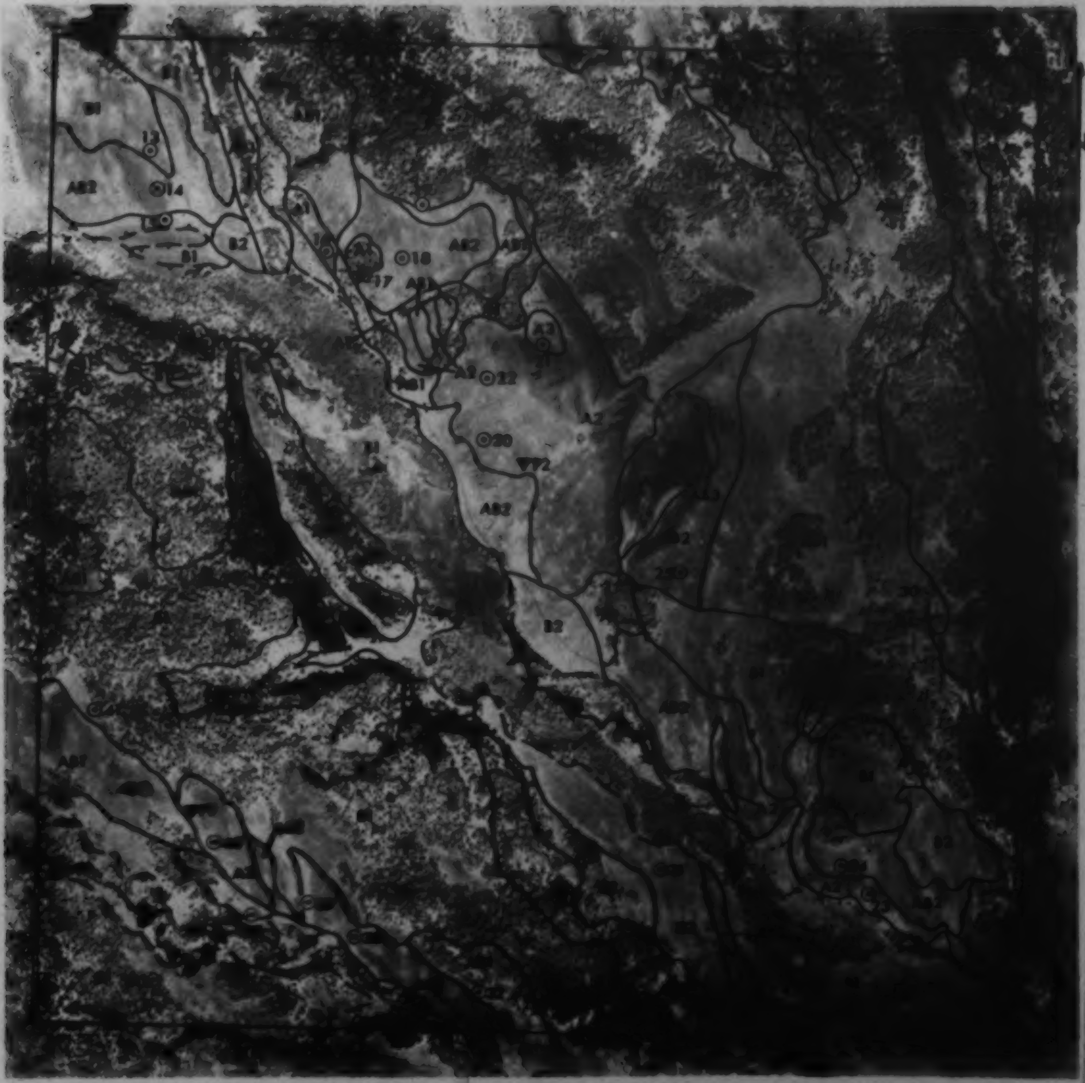

B1
B1
13
A82
14
B1
B2
A81
A82
18
17
A81
A3
22
20
A2
A82
B2

Figure 3-17

Cartwright Section, Pekisko Creek

(Sect. 26-16-4-W5)

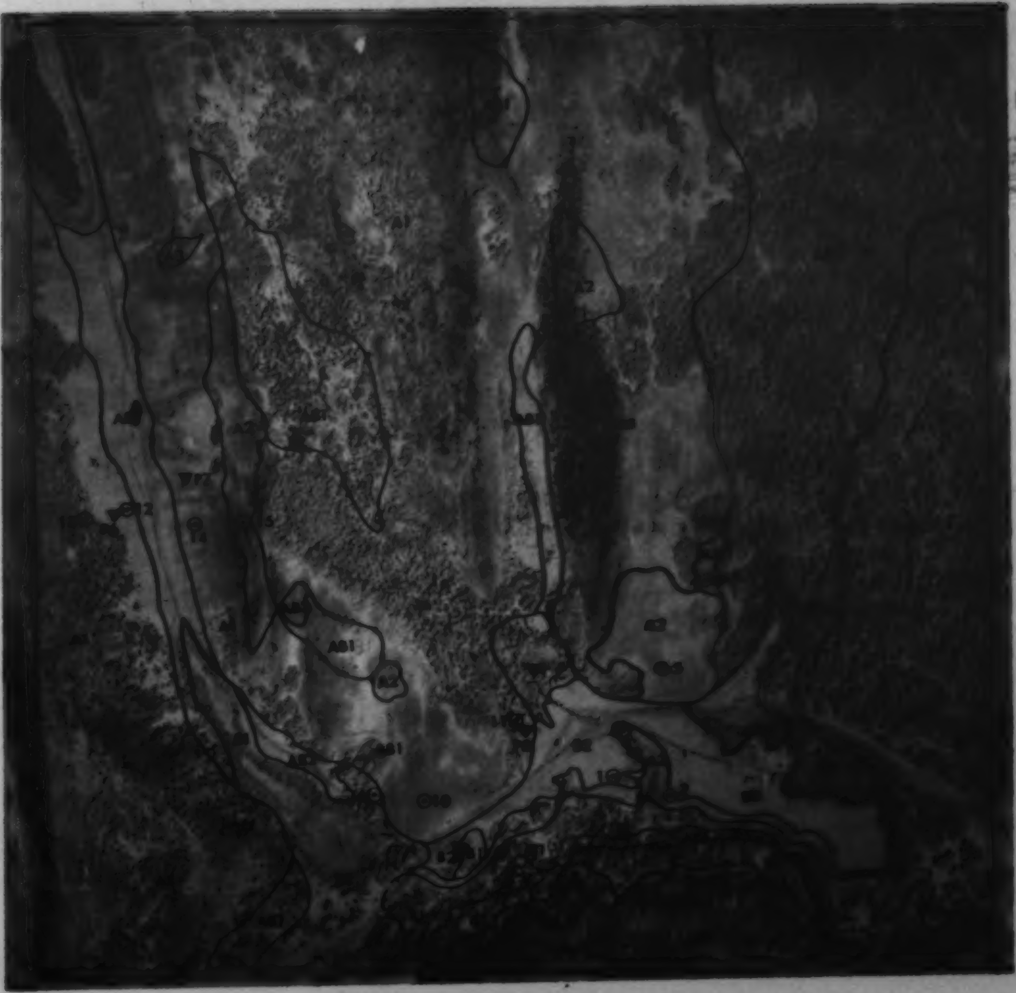
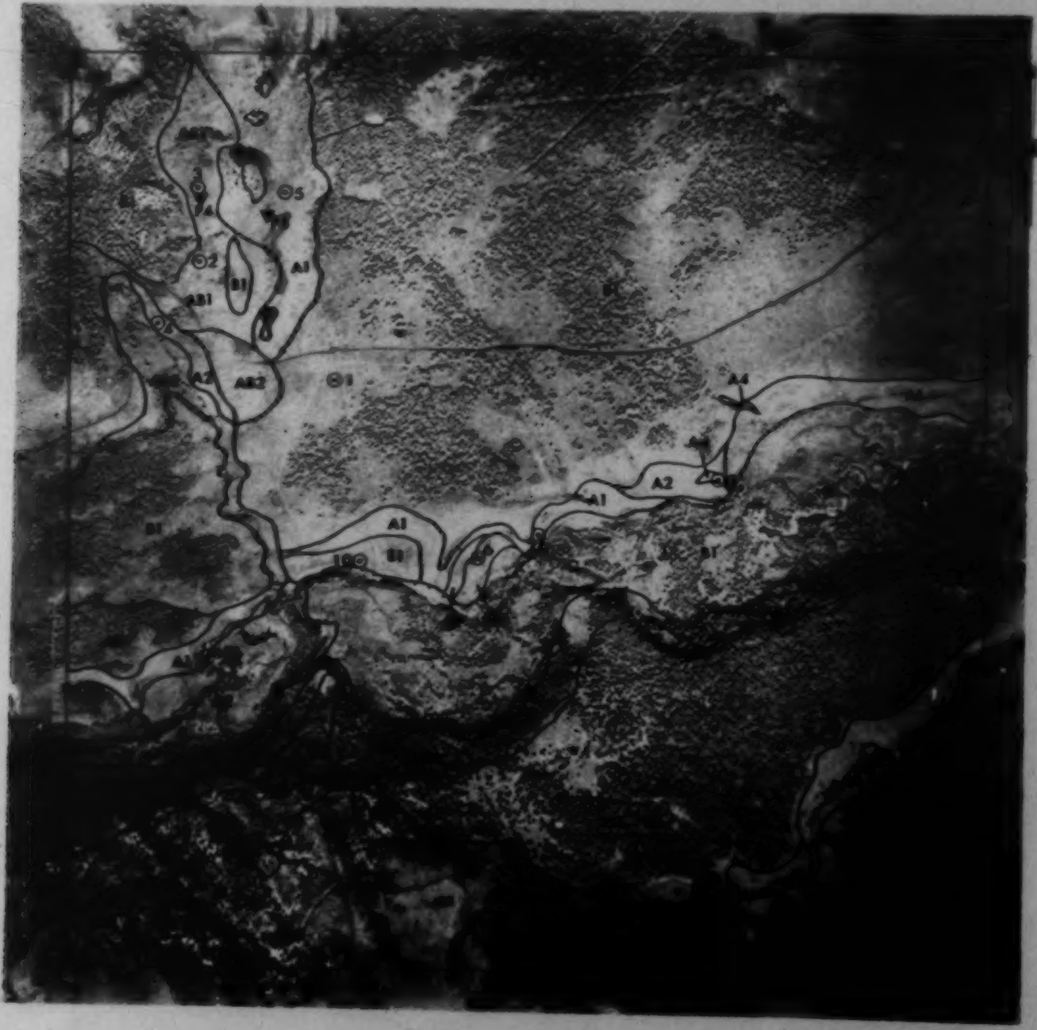

A2
A2
AB1
AB1
A2
AB1

Figure 3-18

Smith Section, Stimson Creek

(Sect. 23-15-3-W5)



⊙5
⊙2
A1
B1
AB1
A2
AB2
⊙1
A4
A2
A1
A1
B1
10⊙
B1
B1
A1

Figure 3-19

Spruce Ranching Section, Stimson Creek

(Sect. 12-16-3-W5)

Figure 3-20

Charmes Section, Three Point Creek

(Sect. 8-21-3-W5)

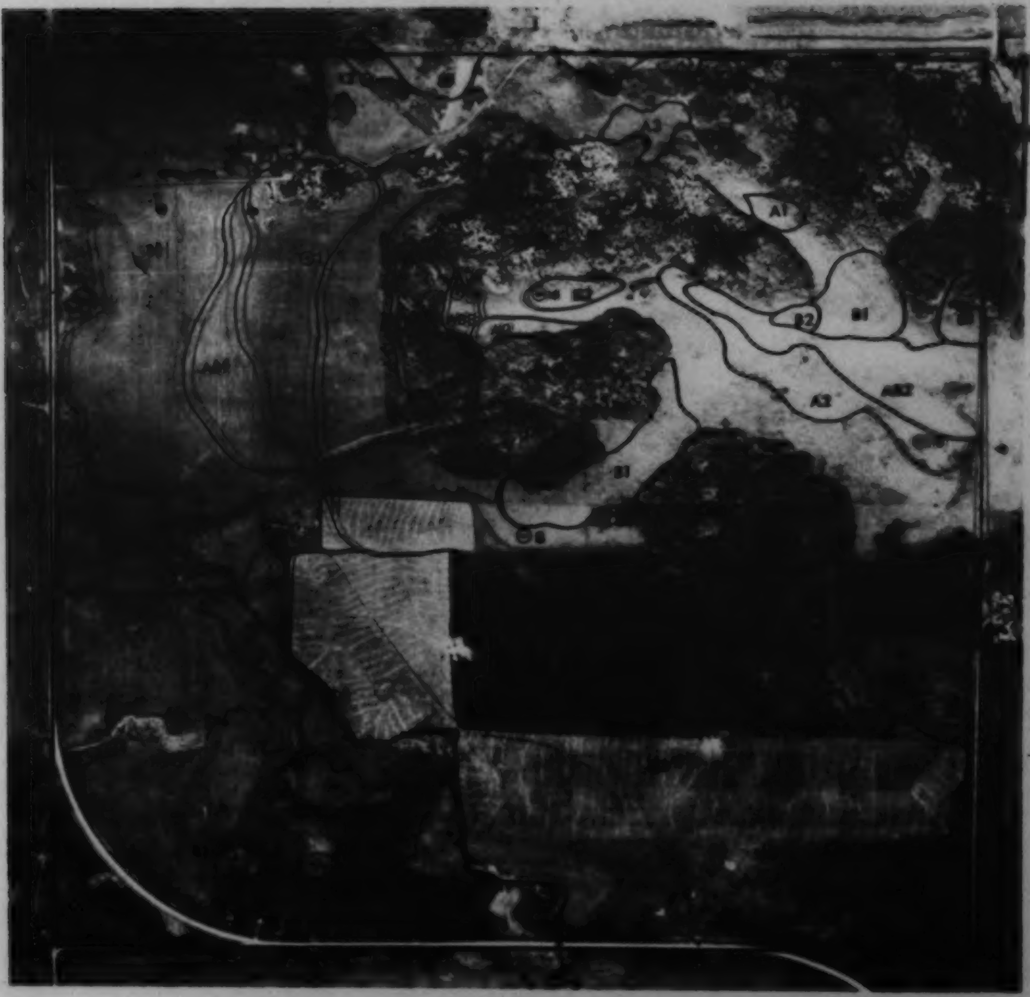

A1
B2
B1
A2
B1

Figure 3-21

McMurtry Section, Three Point Creek

(Sect. 26-20-3-W5)

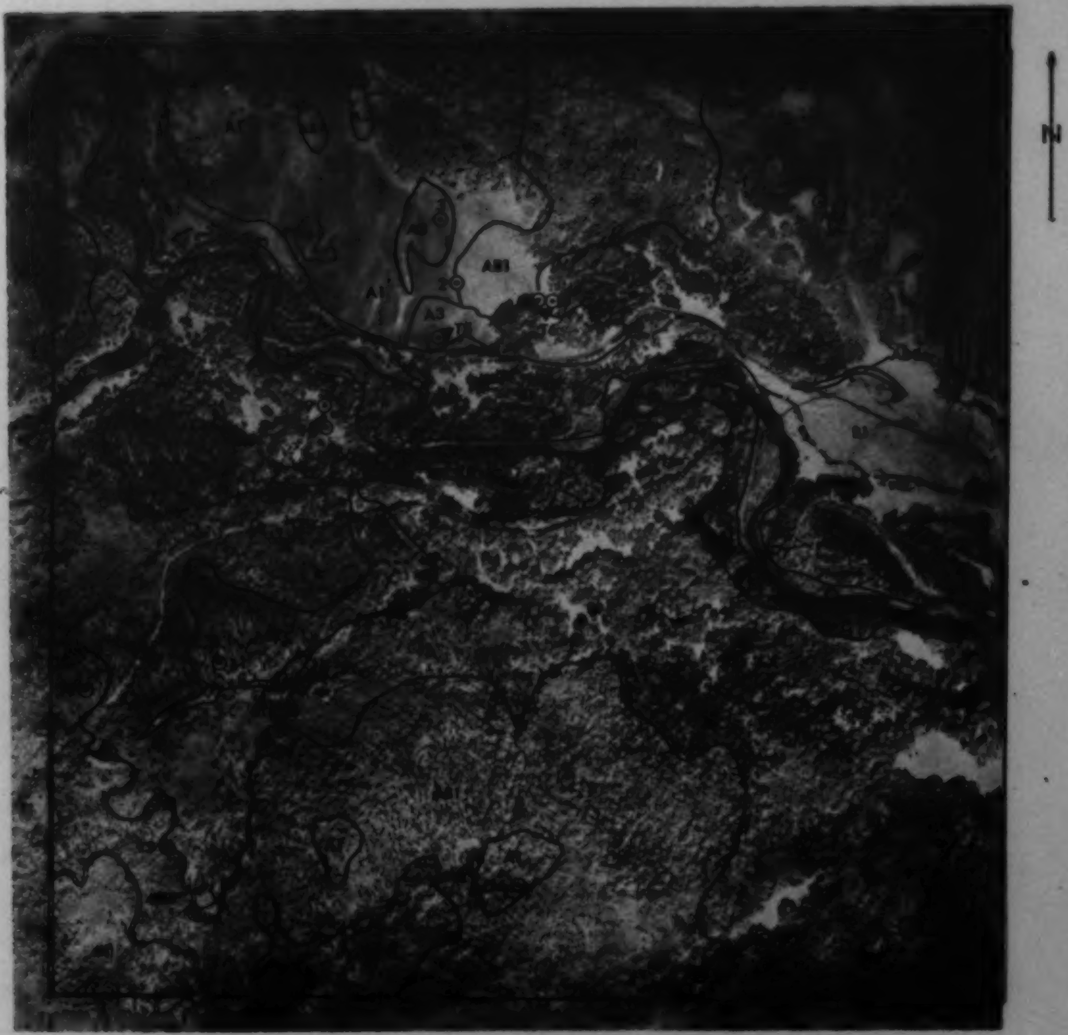


Figure 3-22

Northfork East Section, Three Point Creek

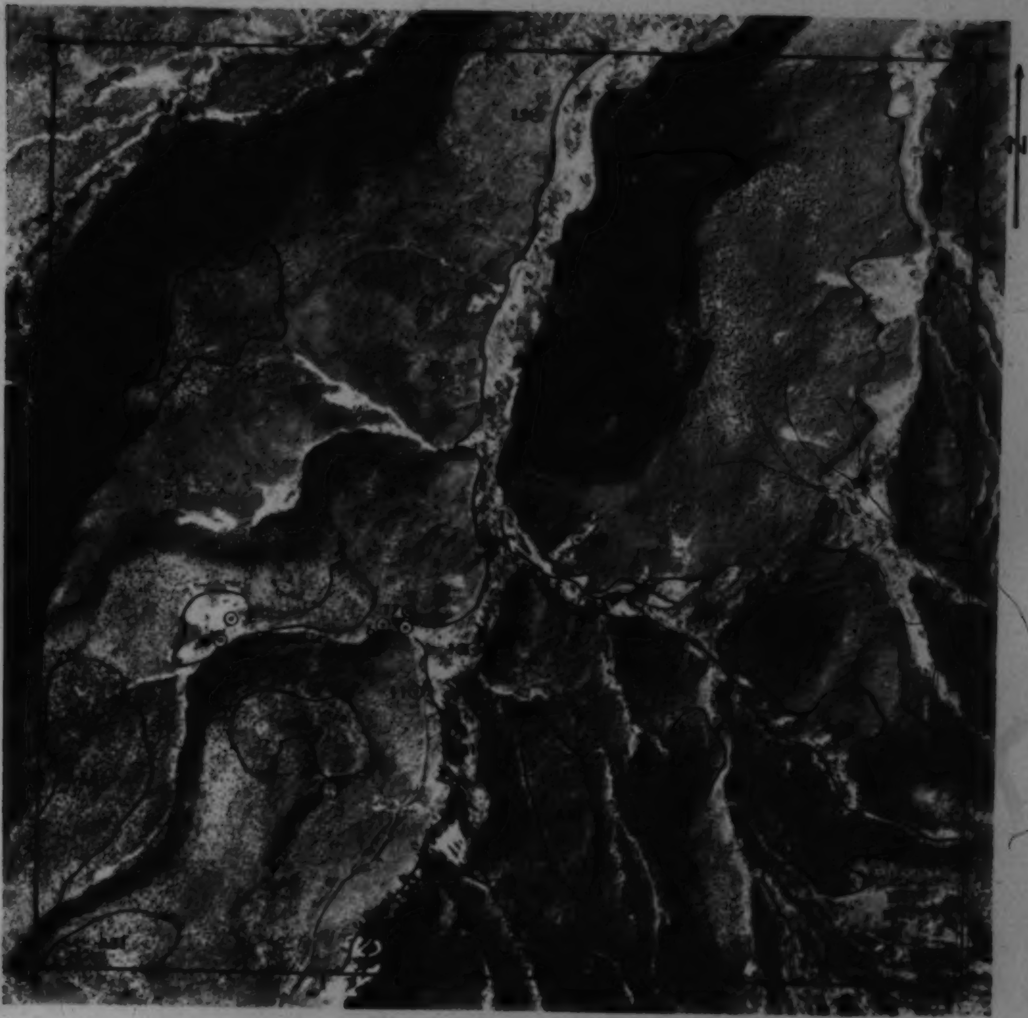


Figure 3-23

Northfork West Section, Three Point Creek

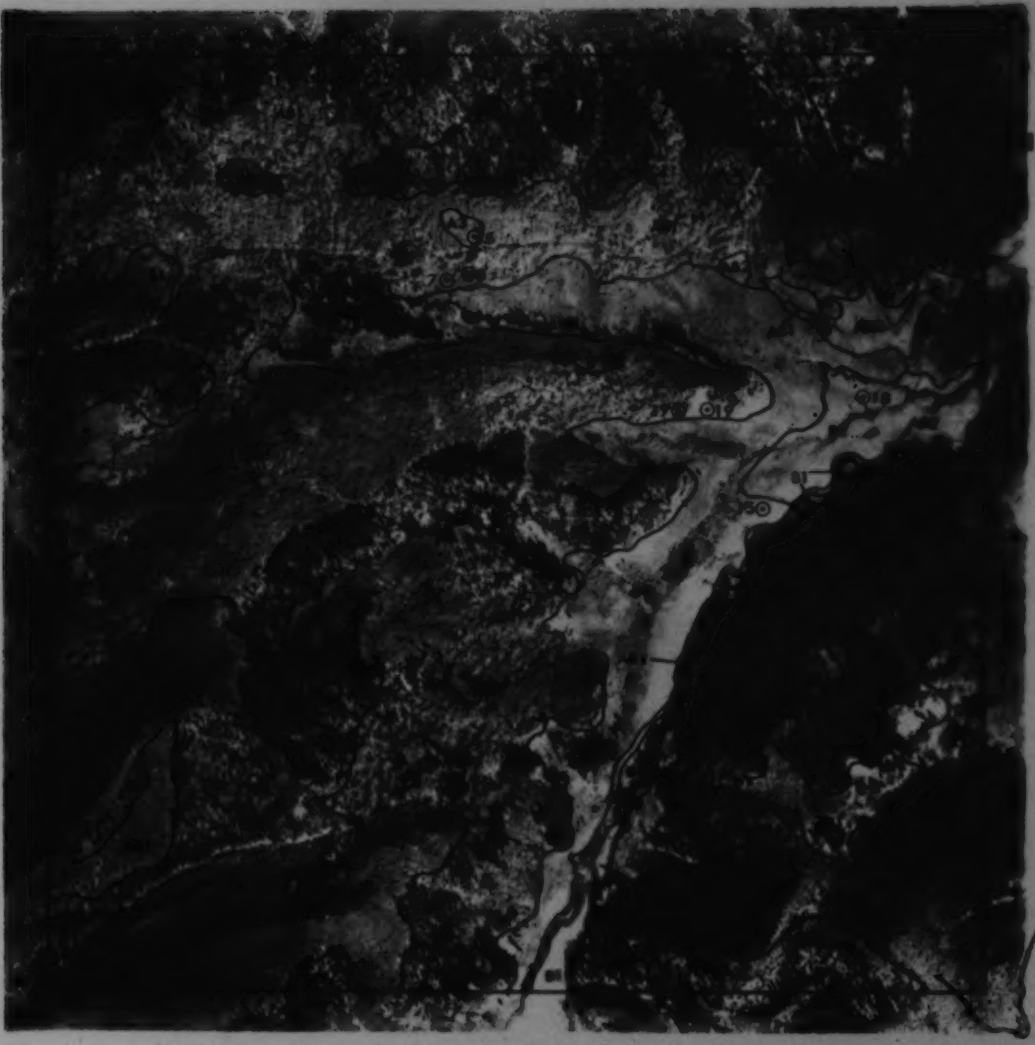


Figure 3-24

Ware Southwest Section, Three Point Creek

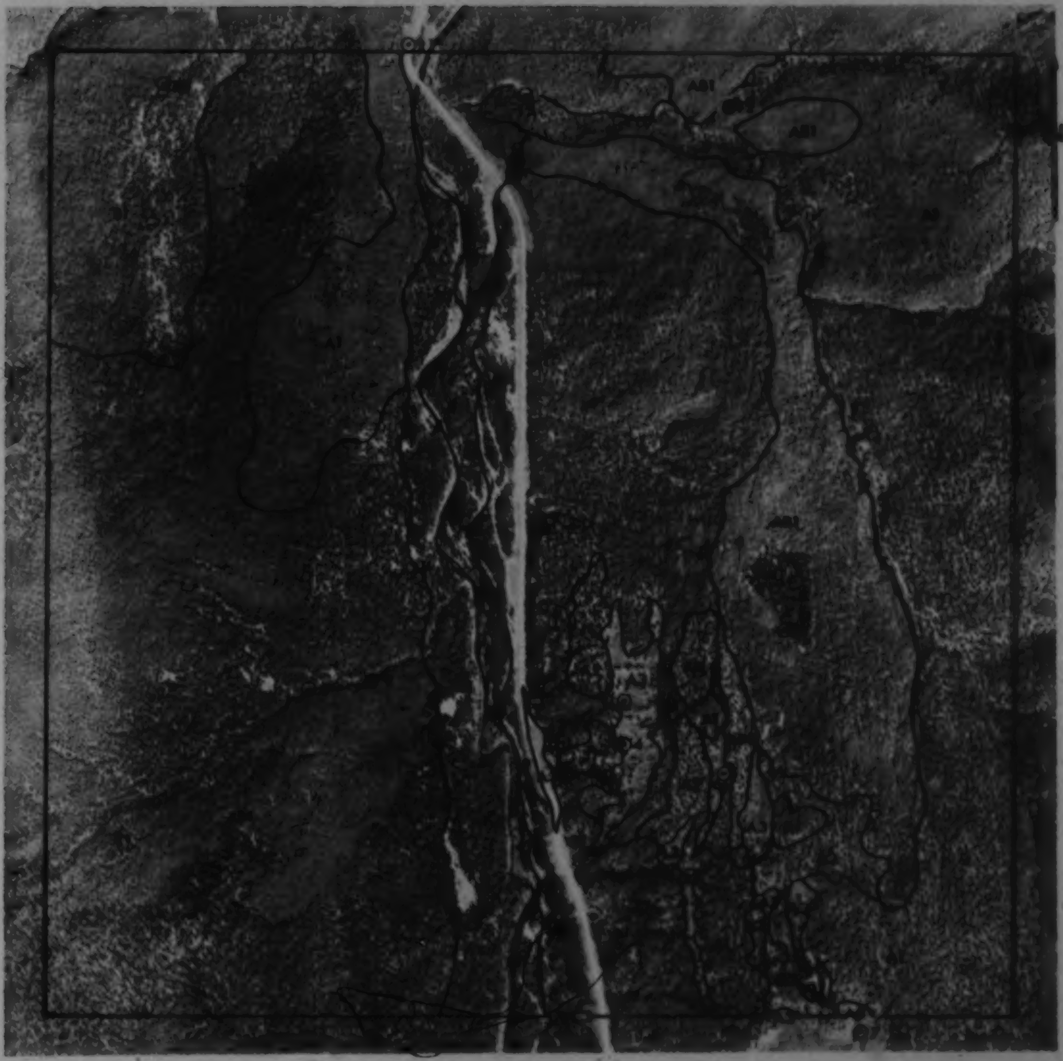

AB1
AB1
A1
AB1

Figure 3-25

Cataract Central Section, Cataract Creek

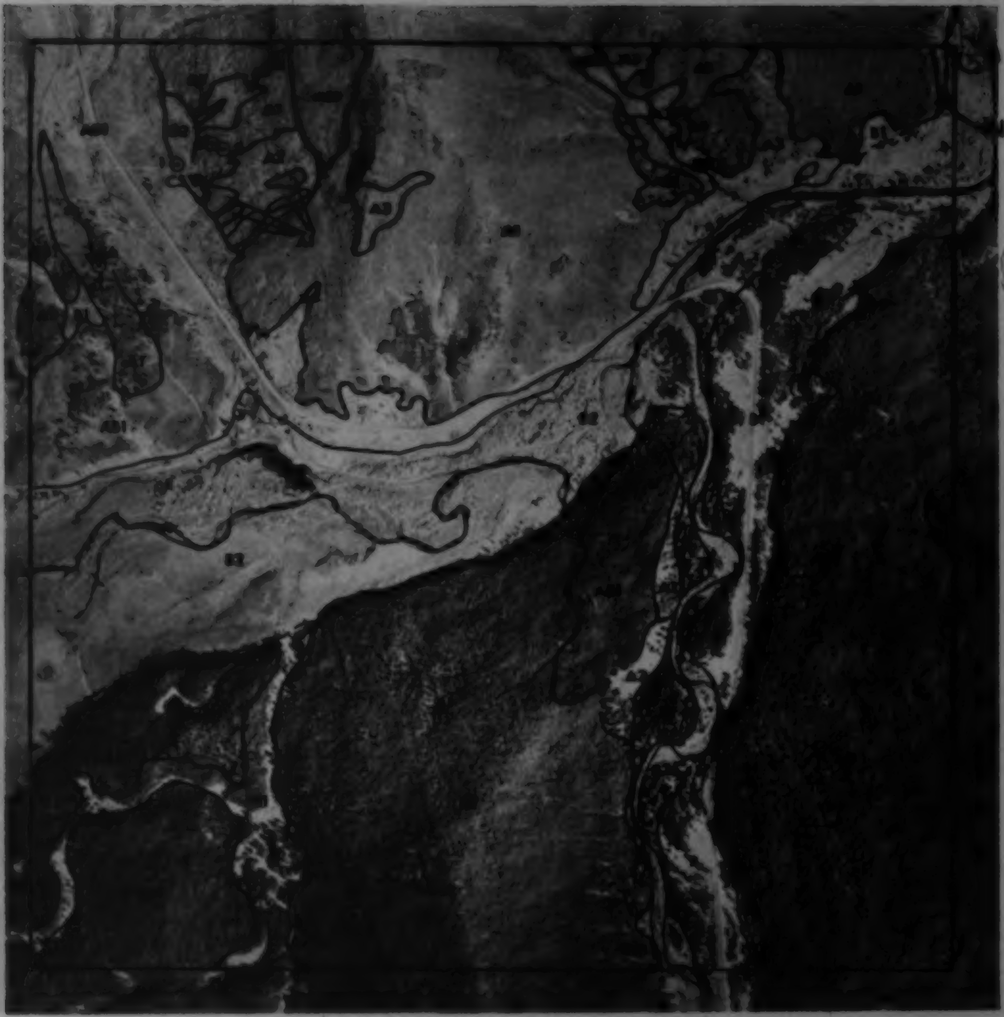


Figure 3-26

Cataract North Section, Catarract Creek

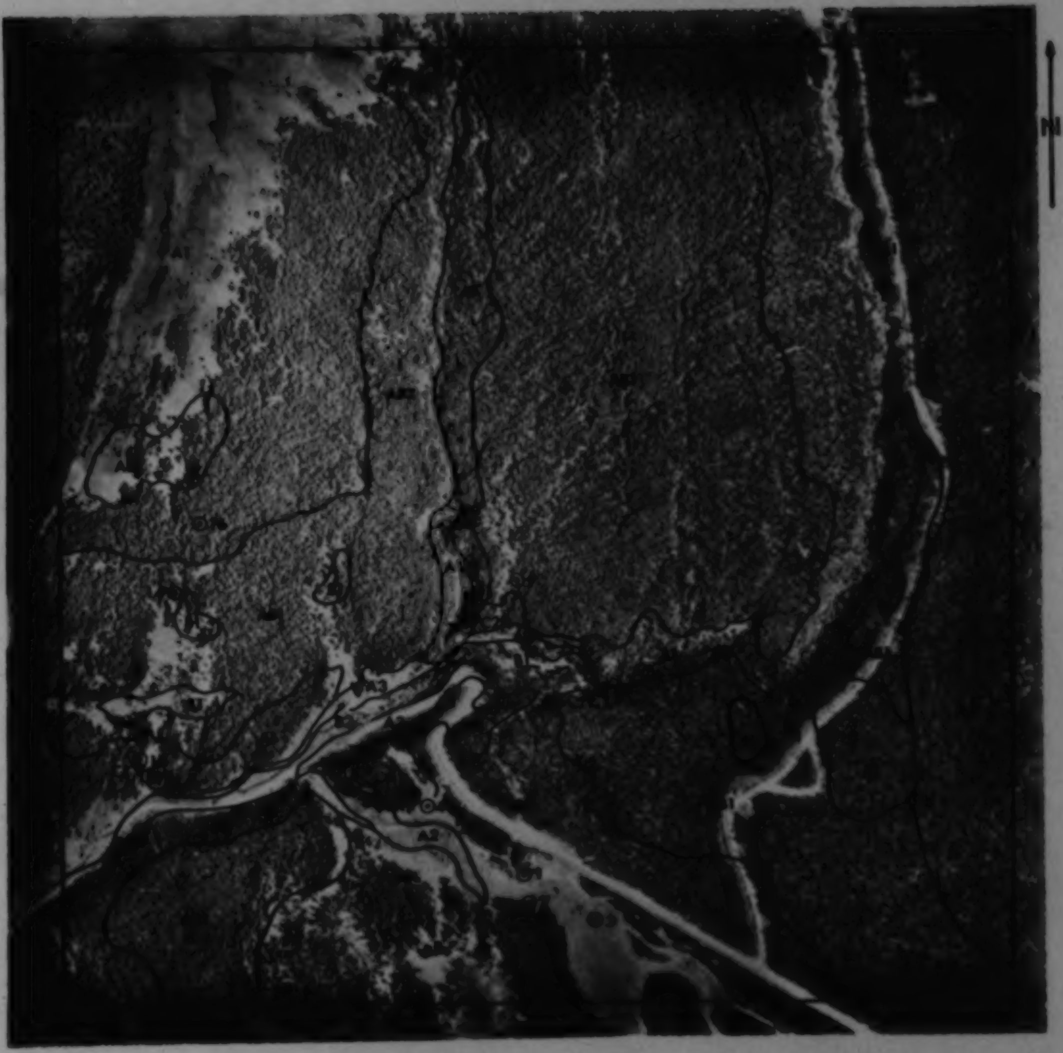


Figure 3-27

Cataract South Section, Cataract Creek

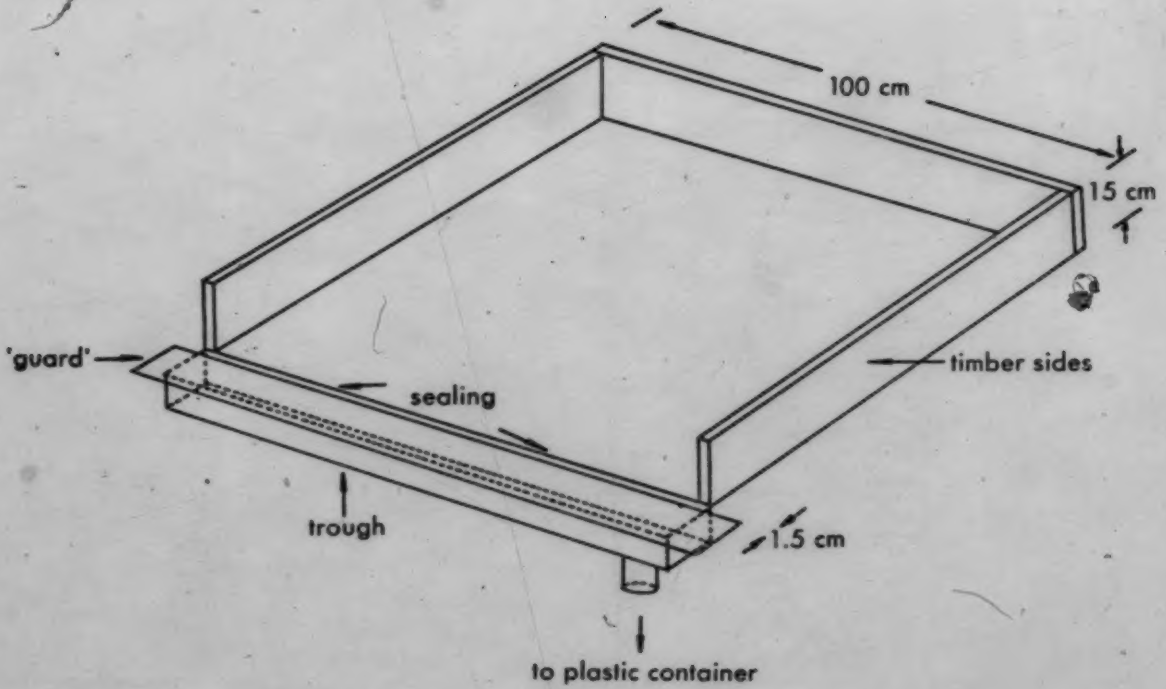

100 cm
15 cm
'guard'
sealing
timber sides
trough
1.5 cm
to plastic container

Figure 4-1
Erosion plot design

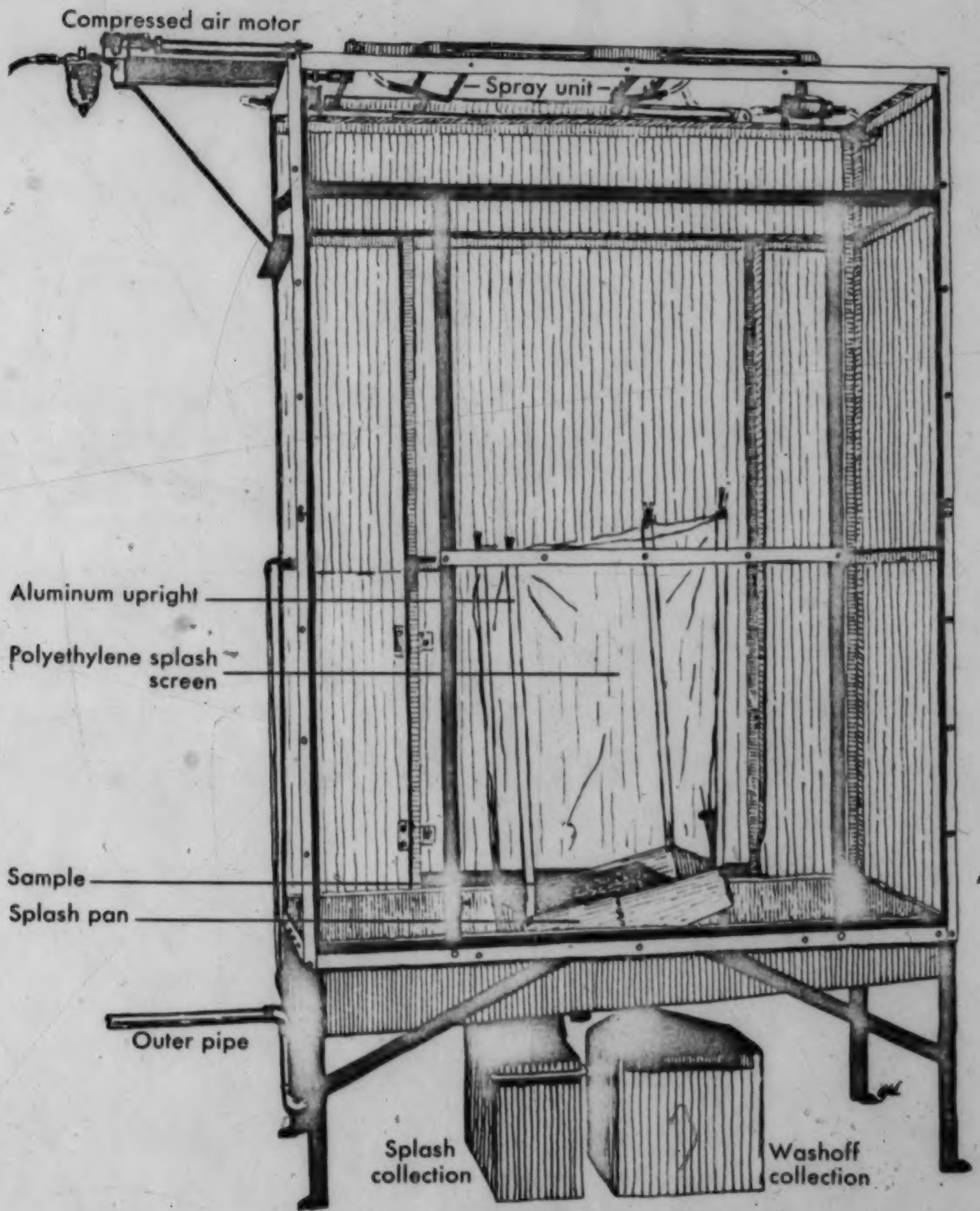

Compressed air motor
Spray unit
Aluminum upright
Polyethylene splash screen
Sample
Splash pan
Outer pipe
Splash collection
Washoff collection

Figure 4-2
The "Edmonton-pattern" rainfall simulator.

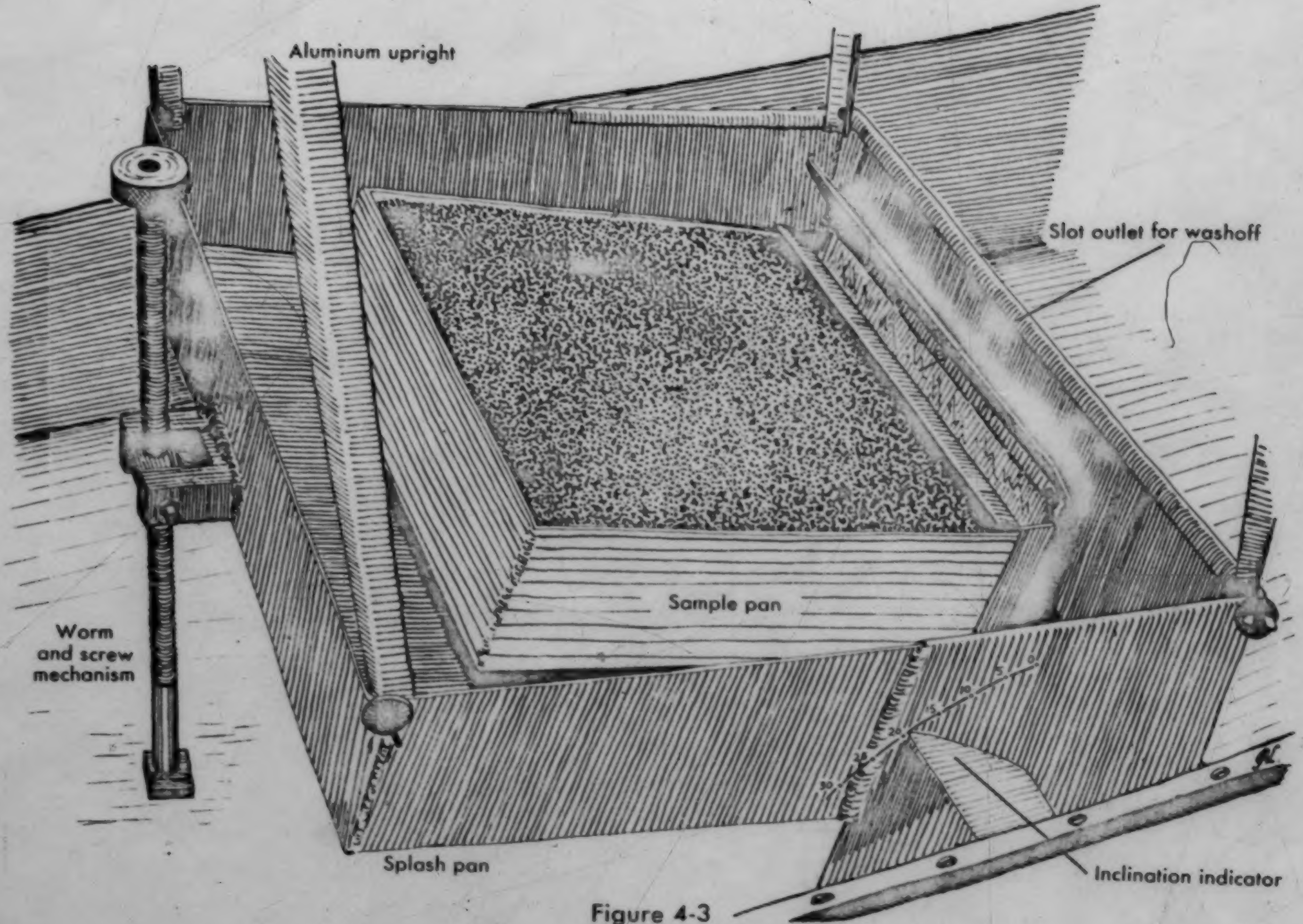
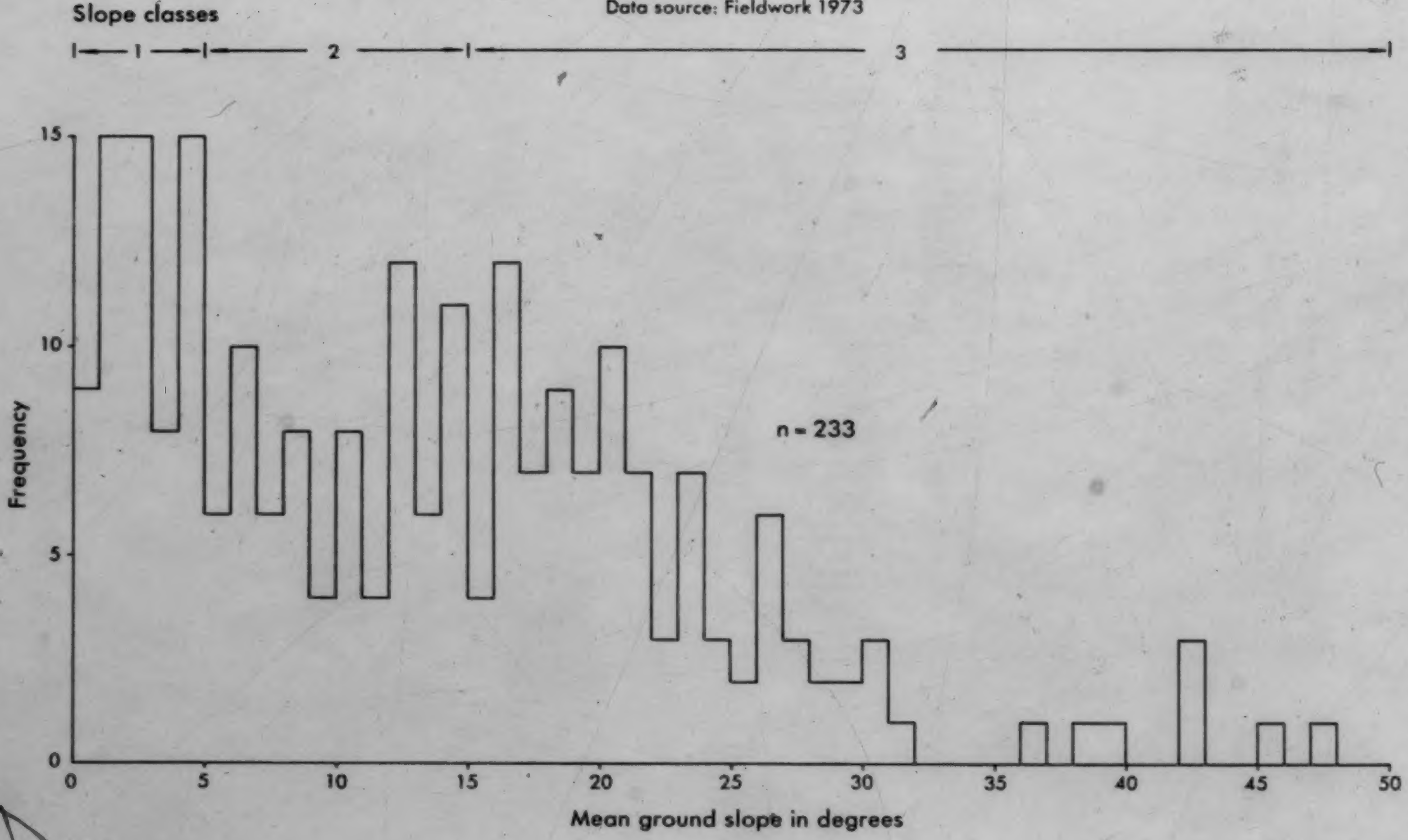

Aluminum upright
Slot outlet for washoff
Worm and screw mechanism
Sample pan
Splash pan
Inclination indicator

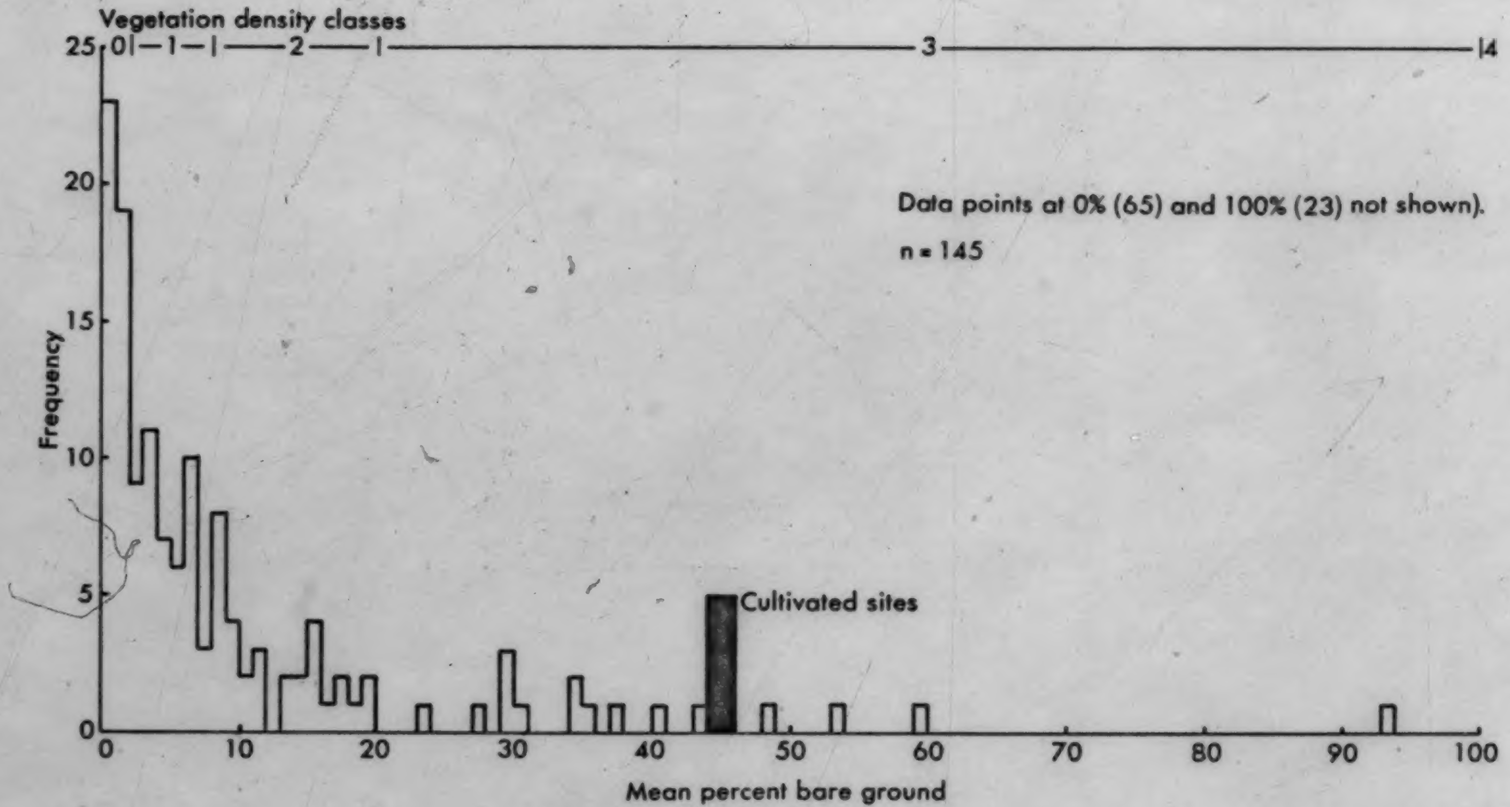
Figure 4-3
Sample pan and splash pan detail.

Figure 4-4

Frequency distribution of mean ground slope

Data source: Fieldwork 1973





Data points at 0% (65) and 100% (23) not shown).

n = 145

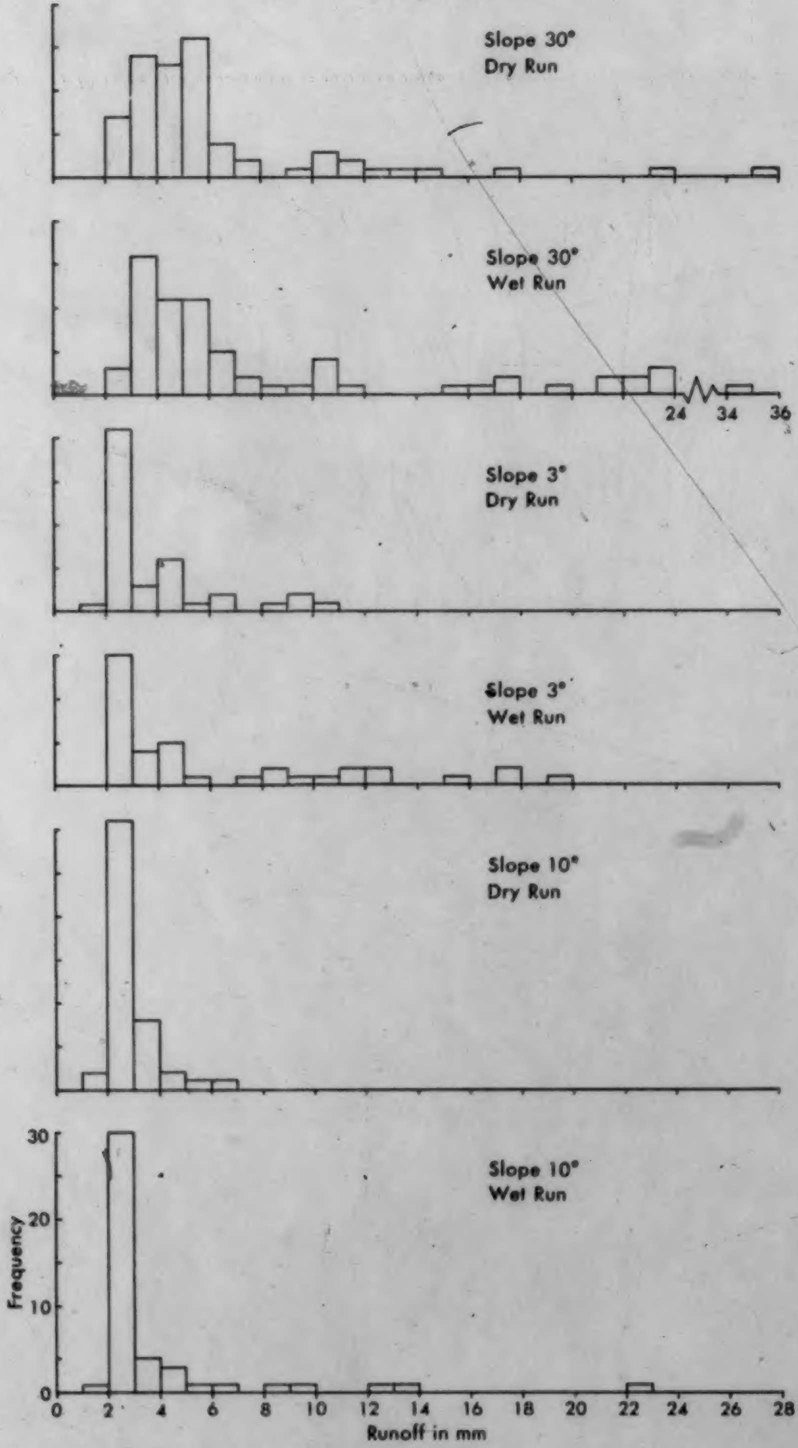
Figure 4-5

Frequency distribution of vegetation cover density.

Source: Fieldwork, 1973.

Figure 5-1

Frequency distribution of runoff amounts for three test slopes and two moisture conditions



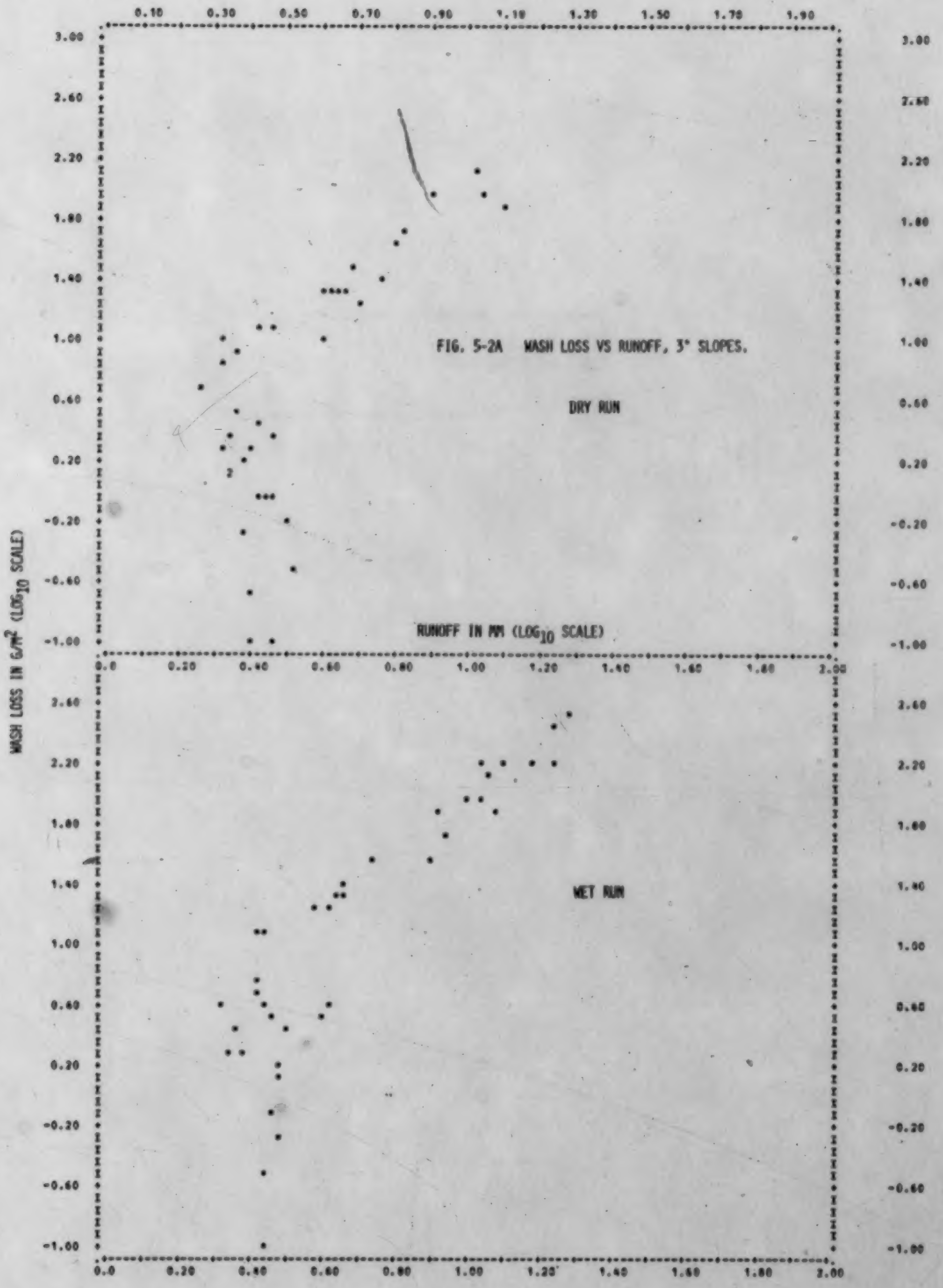


FIG. 5-2A WASH LOSS VS RUNOFF, 3° SLOPES.

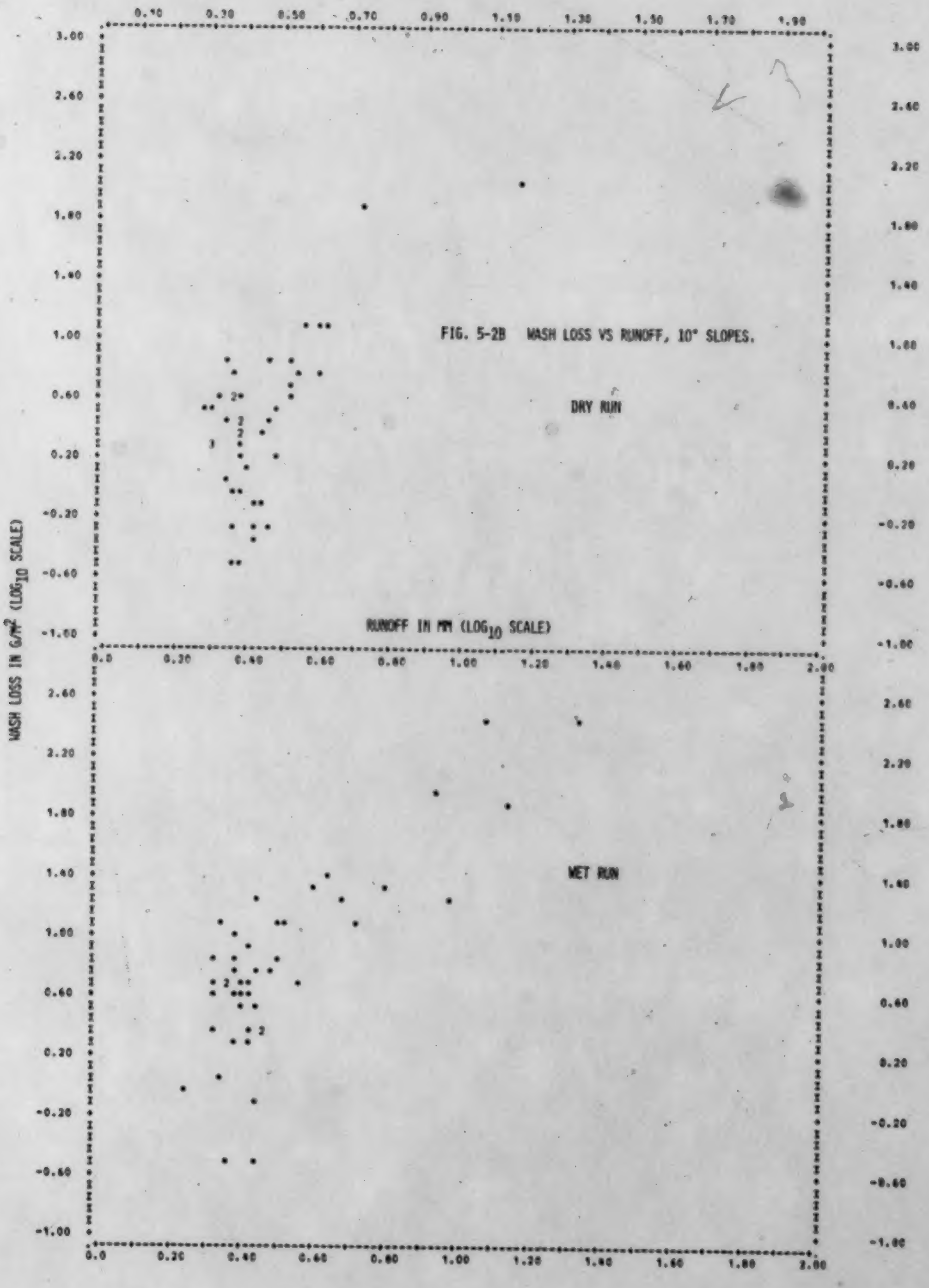


FIG. 5-2B WASH LOSS VS RUNOFF, 10° SLOPES.

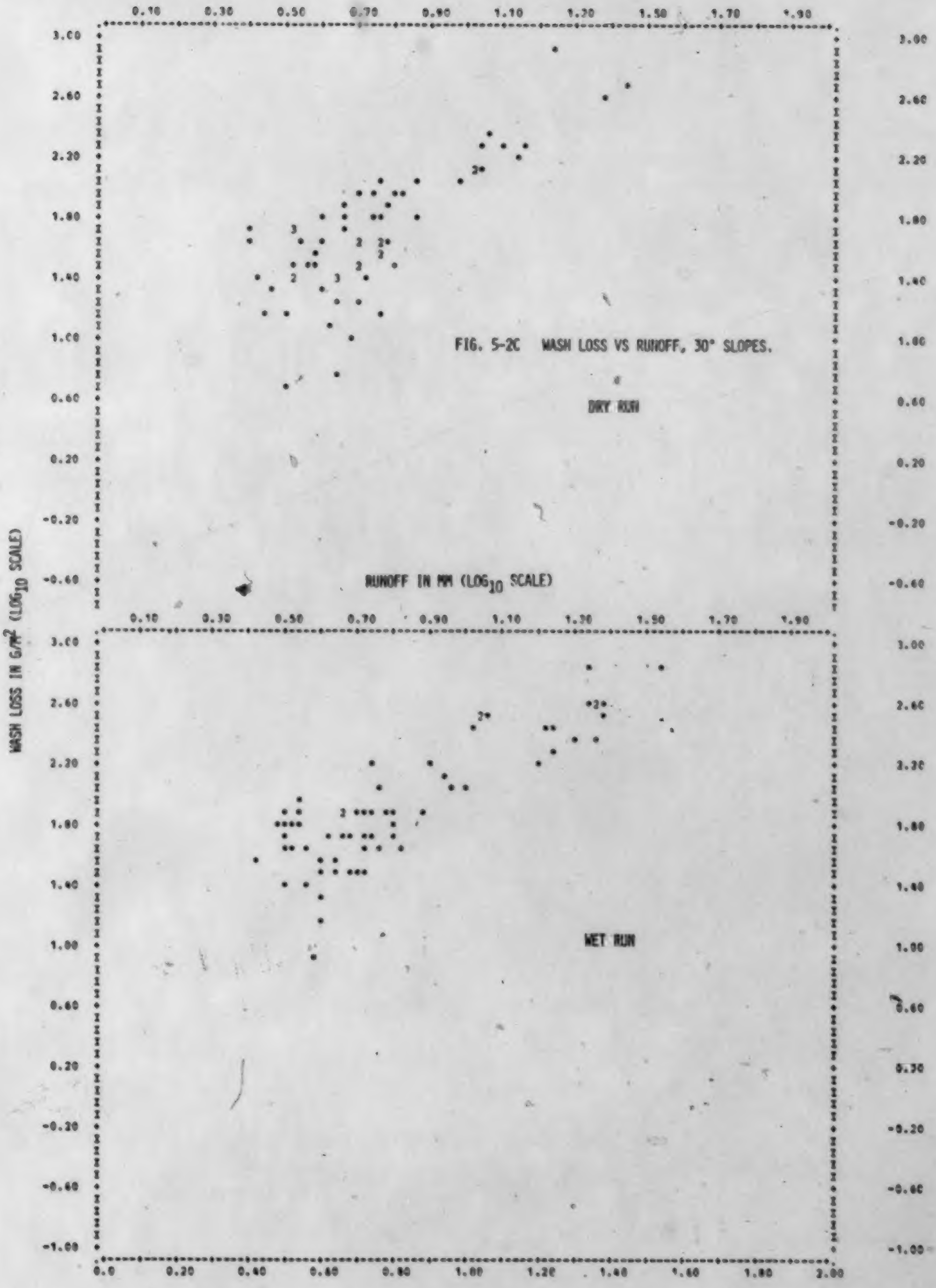


FIG. 5-2C WASH LOSS VS RUNOFF, 30° SLOPES.

Figure 5-3

Correlation profiles of runoff minus direct rainfall vs wash loss for three different test slopes

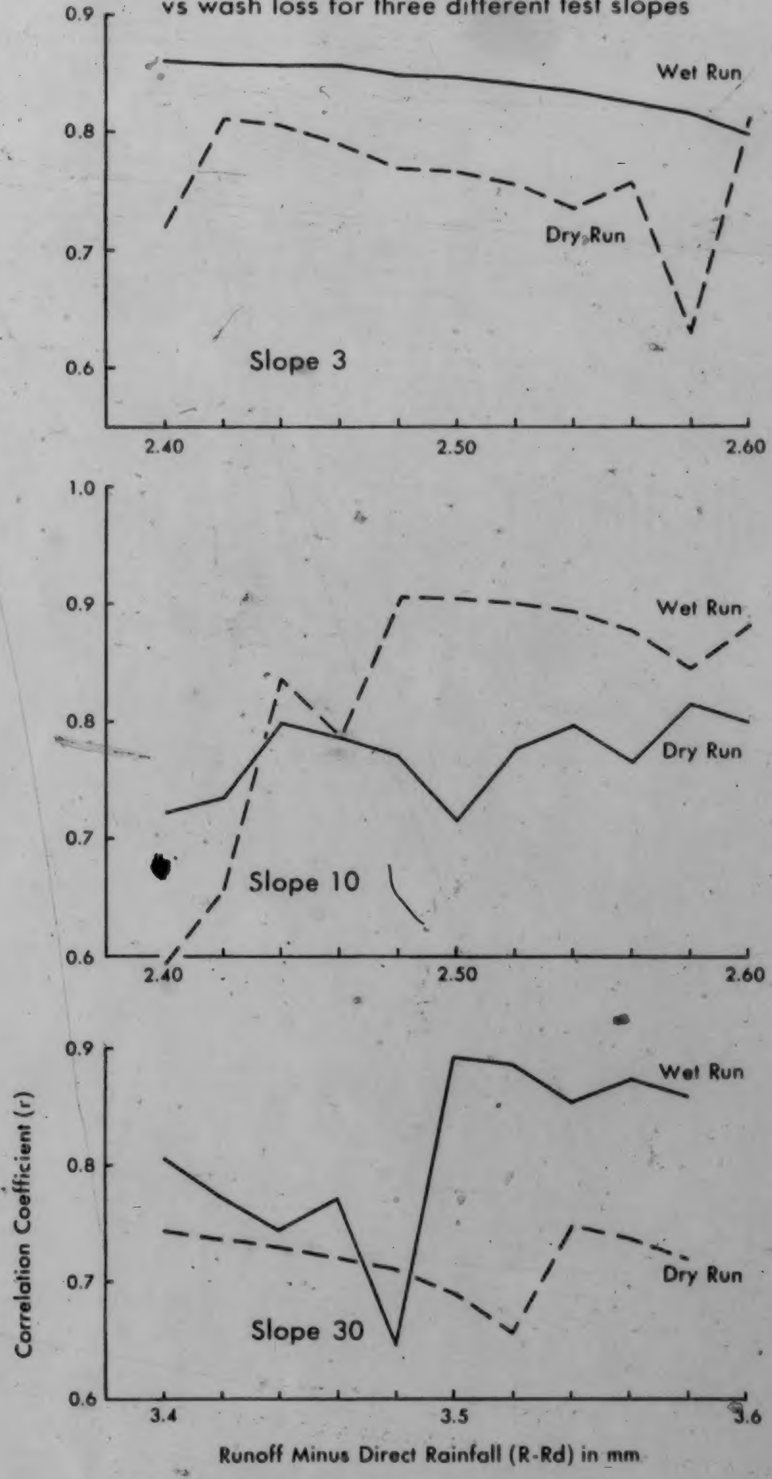


Figure 5-4 a

Frequency distribution of transformed soil loss variables
Subdivided by slope

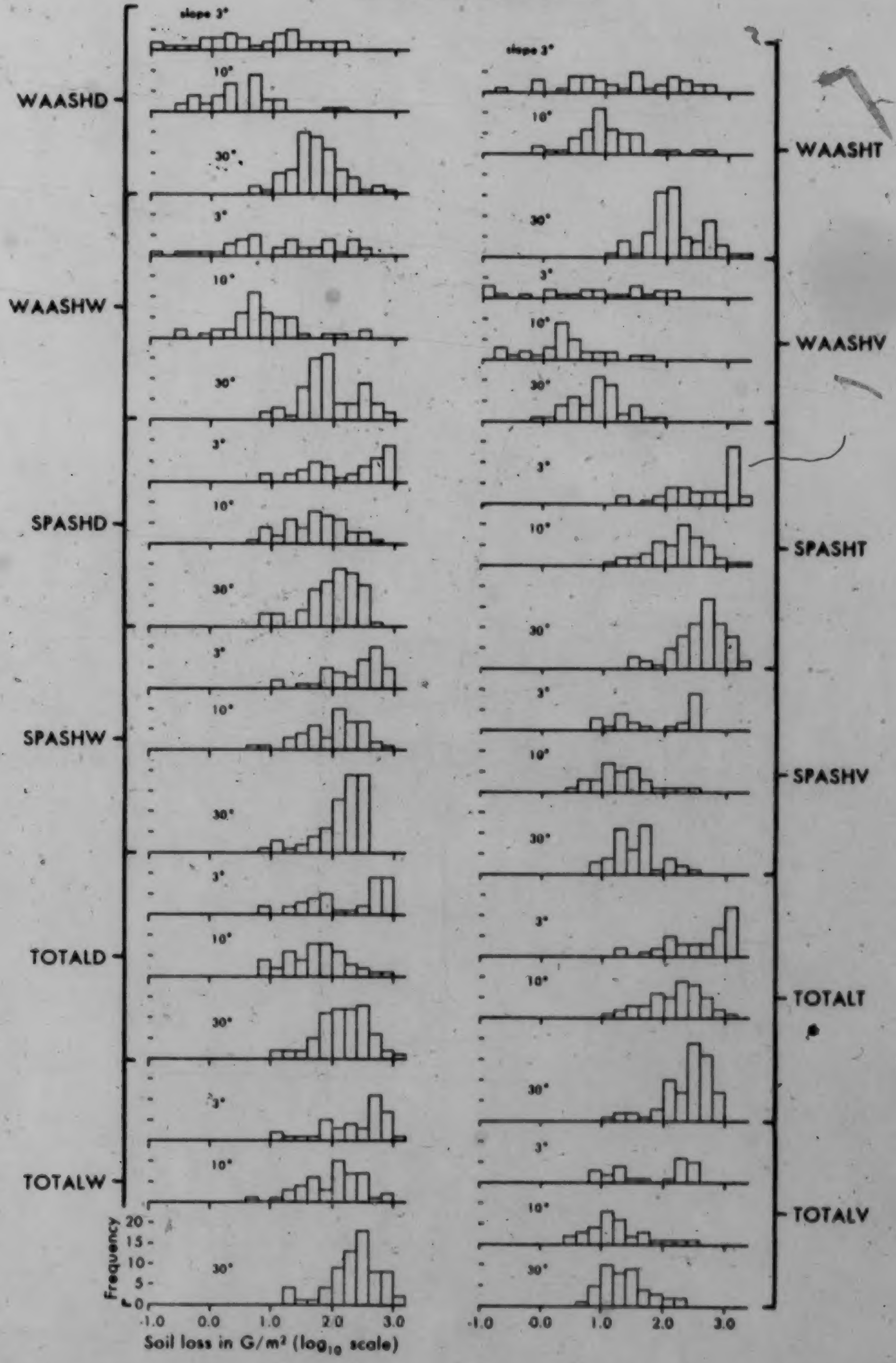
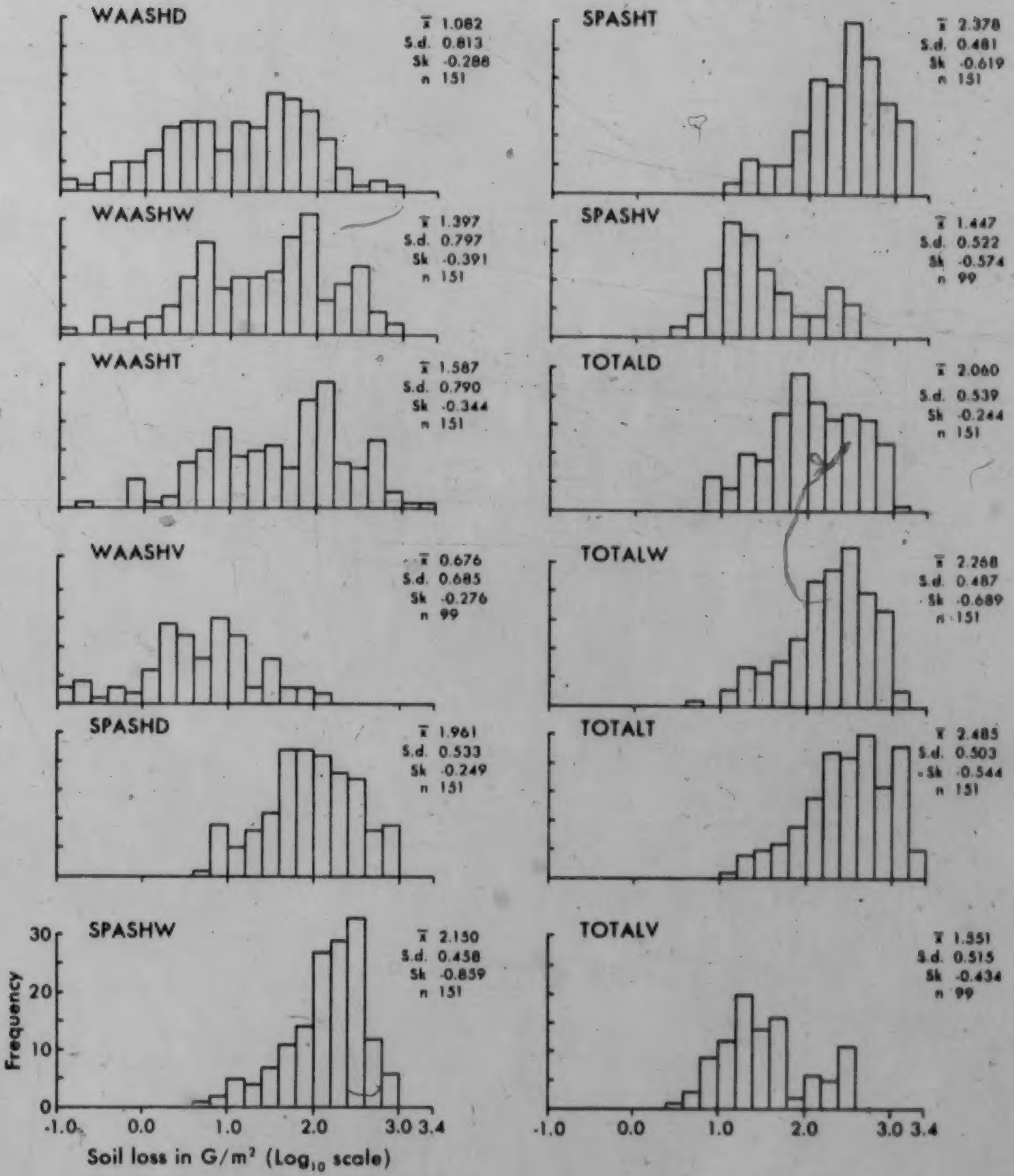


Figure 5-4 b

Frequency distribution of transformed soil loss variables



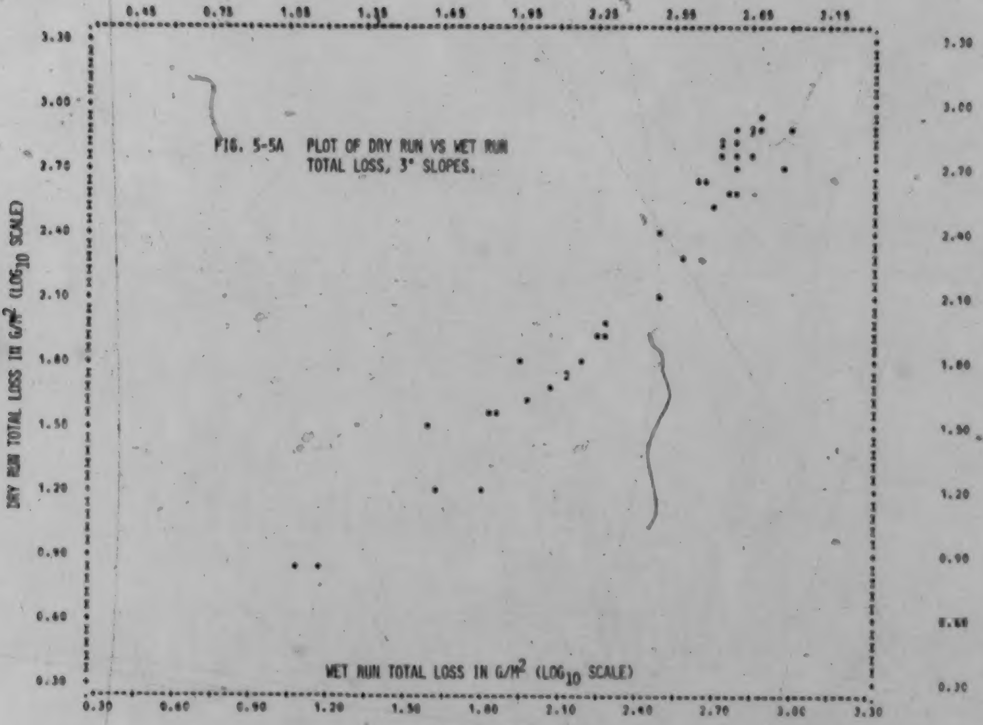


FIG. 5-5A PLOT OF DRY RUN VS WET RUN TOTAL LOSS, 3° SLOPES.

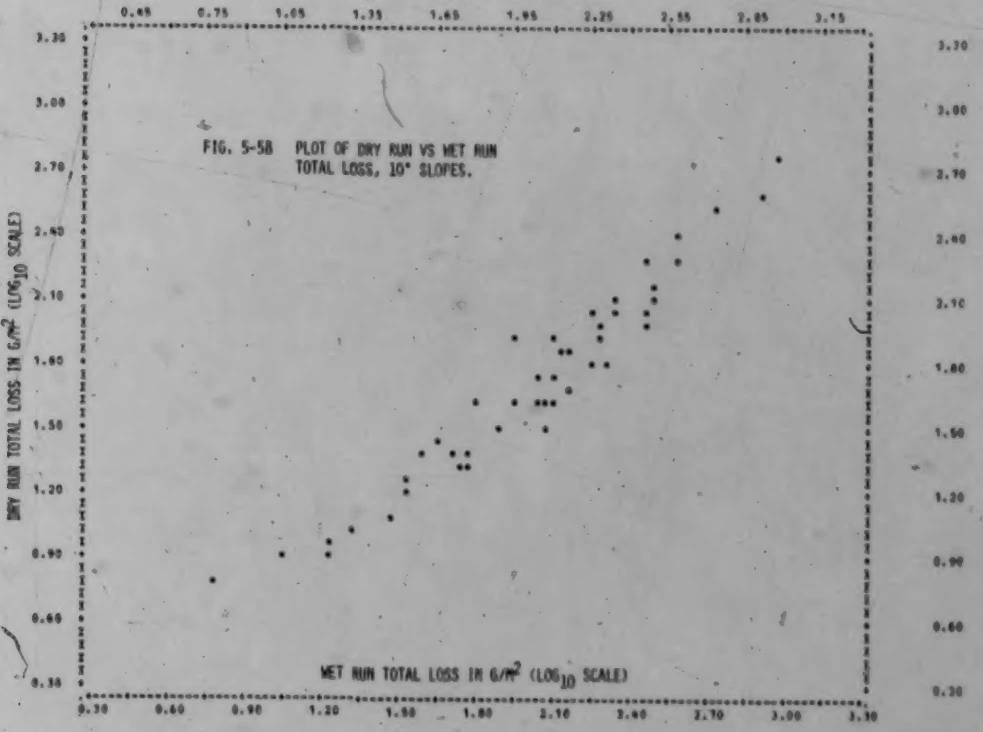


FIG. 5-5B PLOT OF DRY RUN VS WET RUN TOTAL LOSS, 10° SLOPES.

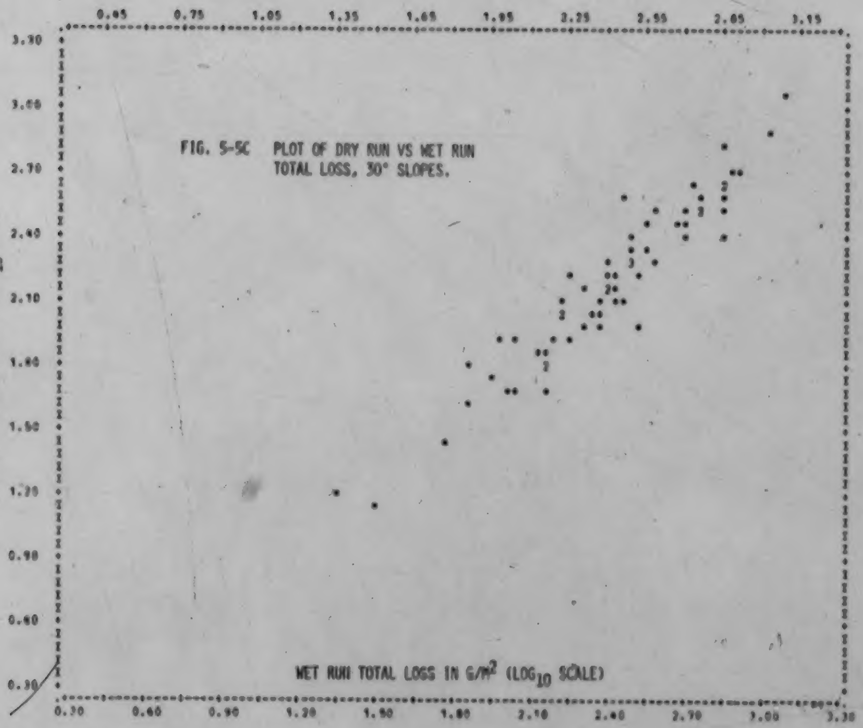


FIG. 5-5C PLOT OF DRY RUN VS WET RUN TOTAL LOSS, 30° SLOPES.

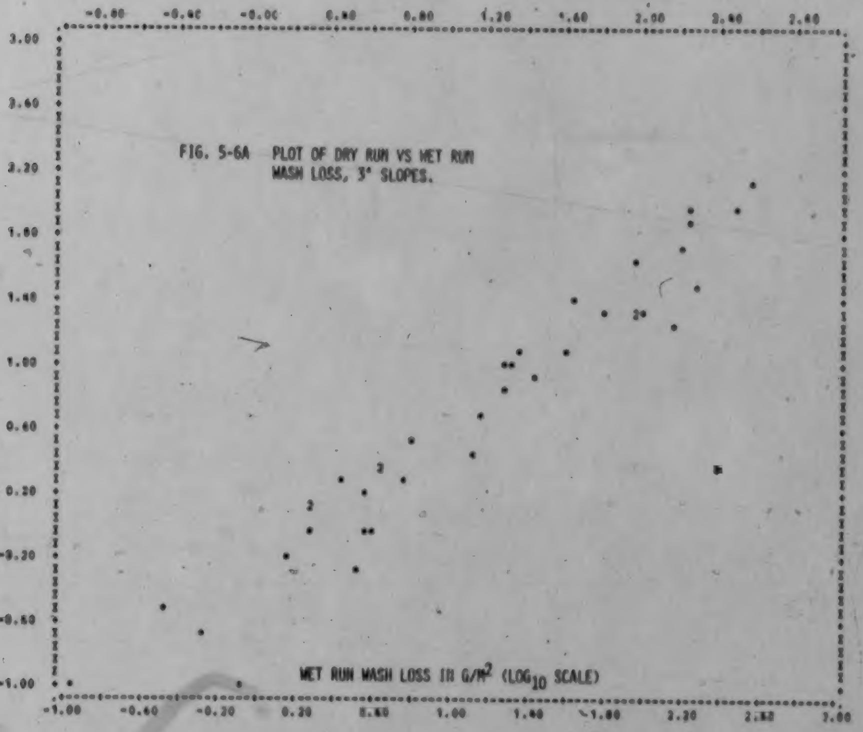


FIG. 5-6A PLOT OF DRY RUN VS WET RUN WASH LOSS, 3° SLOPES.

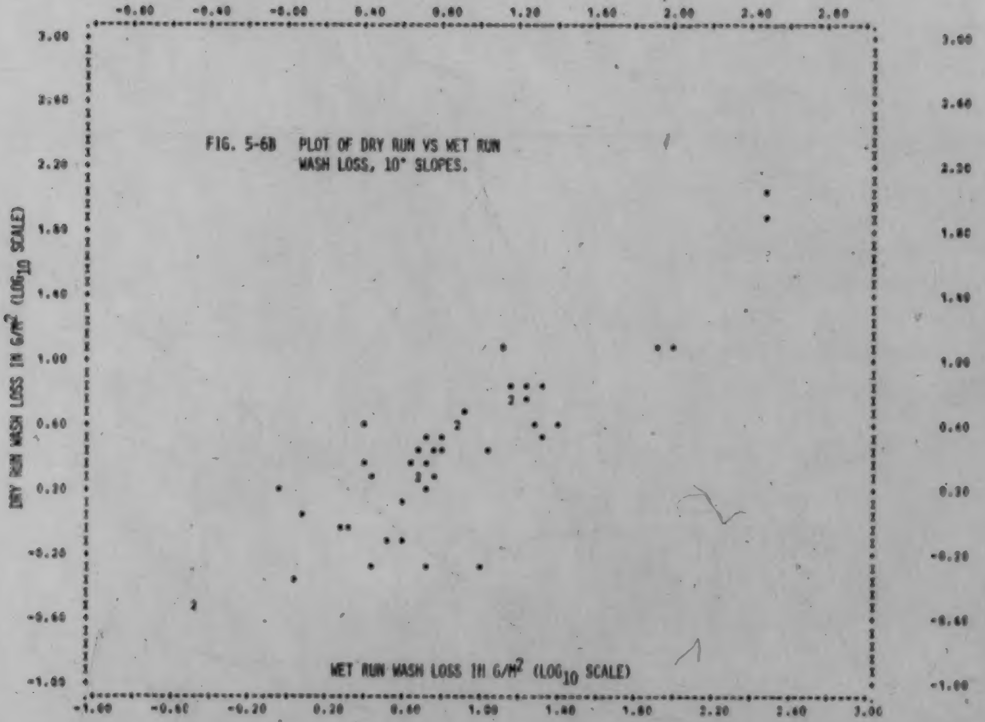


FIG. 5-6B PLOT OF DRY RUN VS WET RUN WASH LOSS, 10° SLOPES.

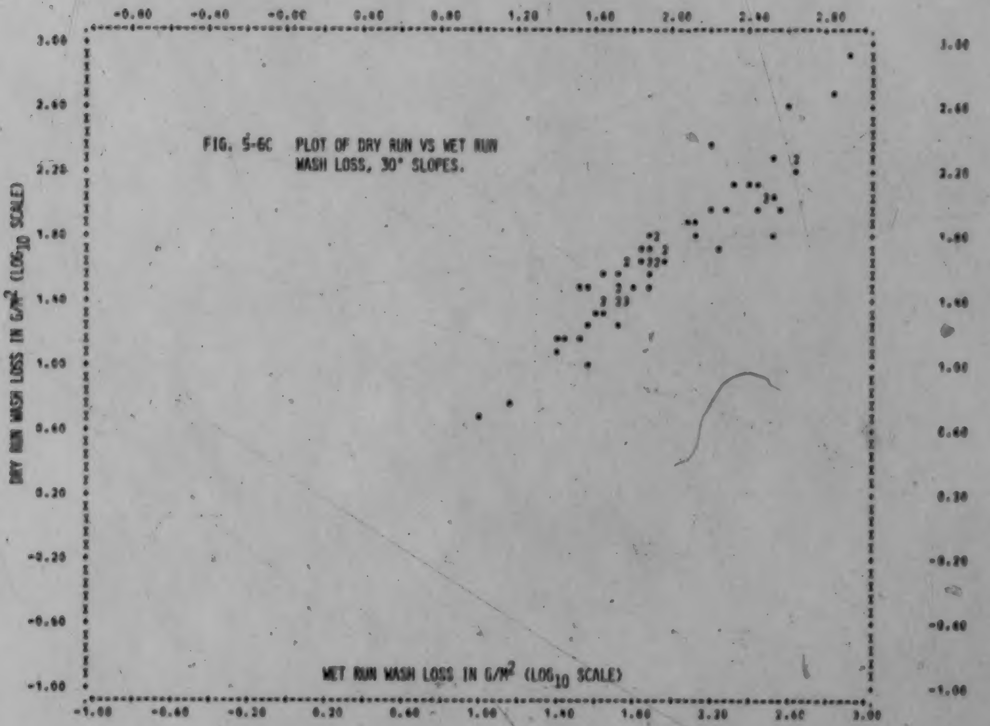


FIG. 5-6C PLOT OF DRY RUN VS WET RUN WASH LOSS, 30° SLOPES.

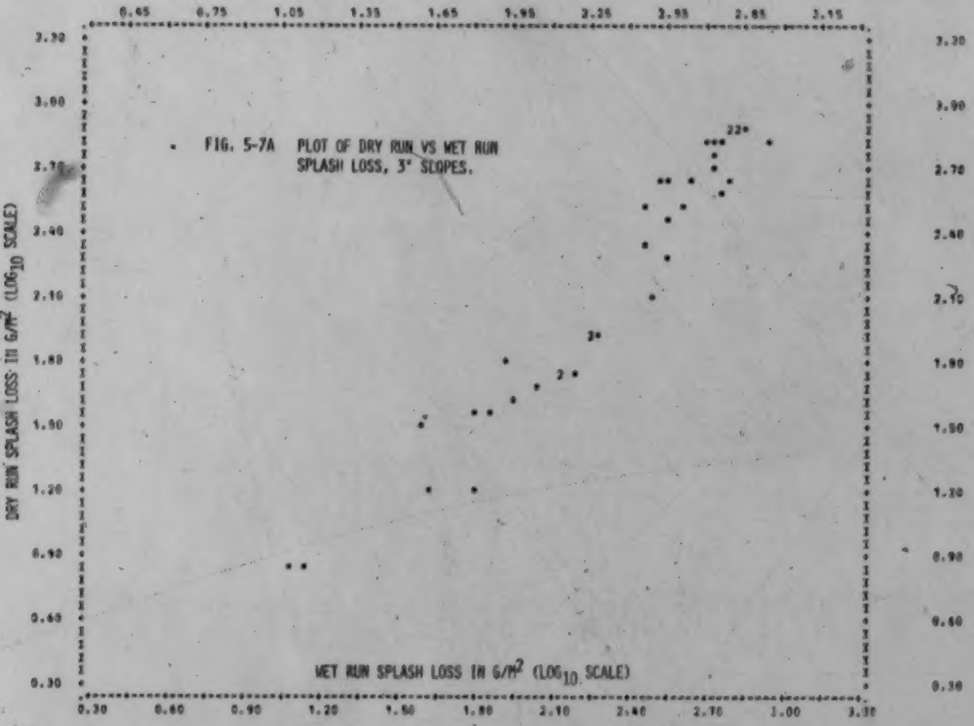


FIG. 5-7A PLOT OF DRY RUN VS WET RUN SPLASH LOSS, 3° SLOPES.

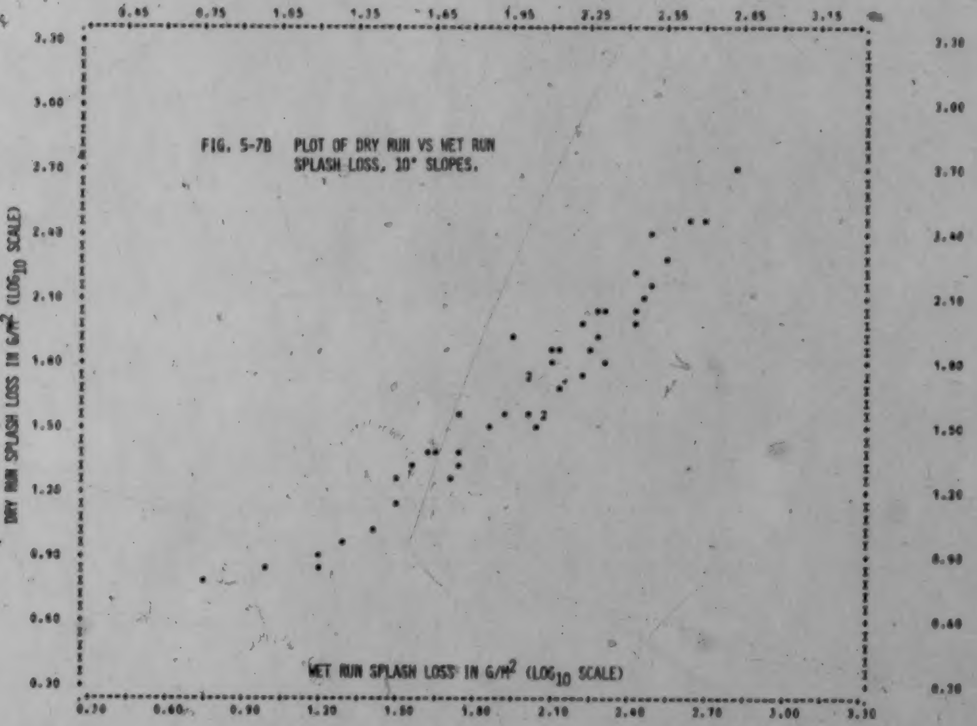


FIG. 5-7B PLOT OF DRY RUN VS WET RUN SPLASH LOSS, 10° SLOPES.

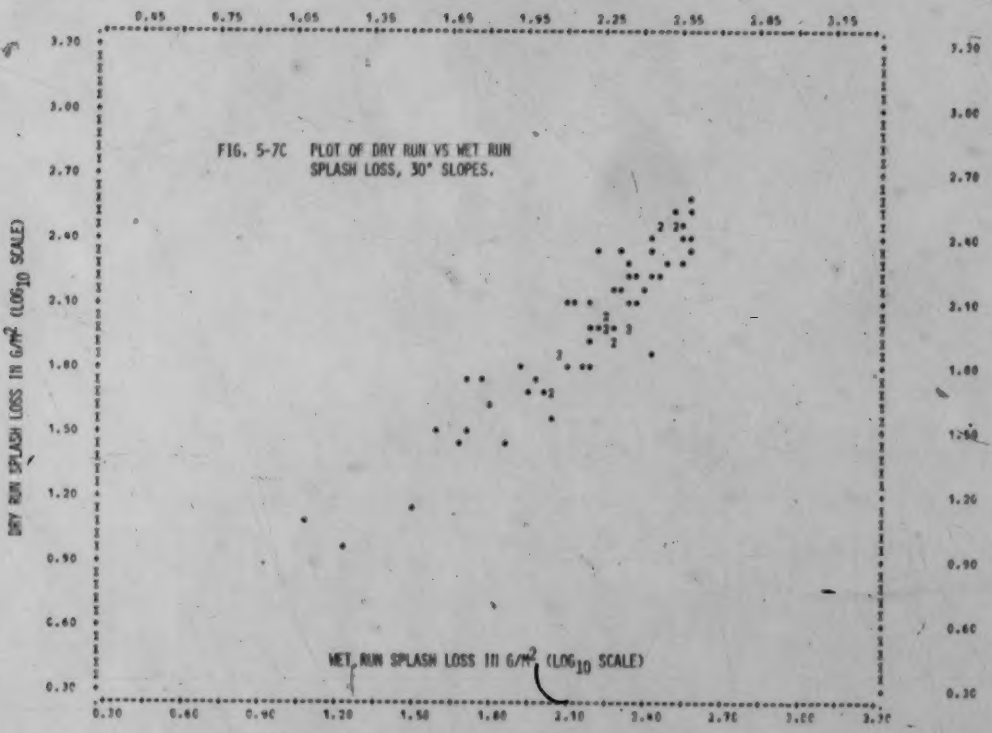


FIG. 5-7C PLOT OF DRY RUN VS WET RUN SPLASH LOSS, 30° SLOPES.

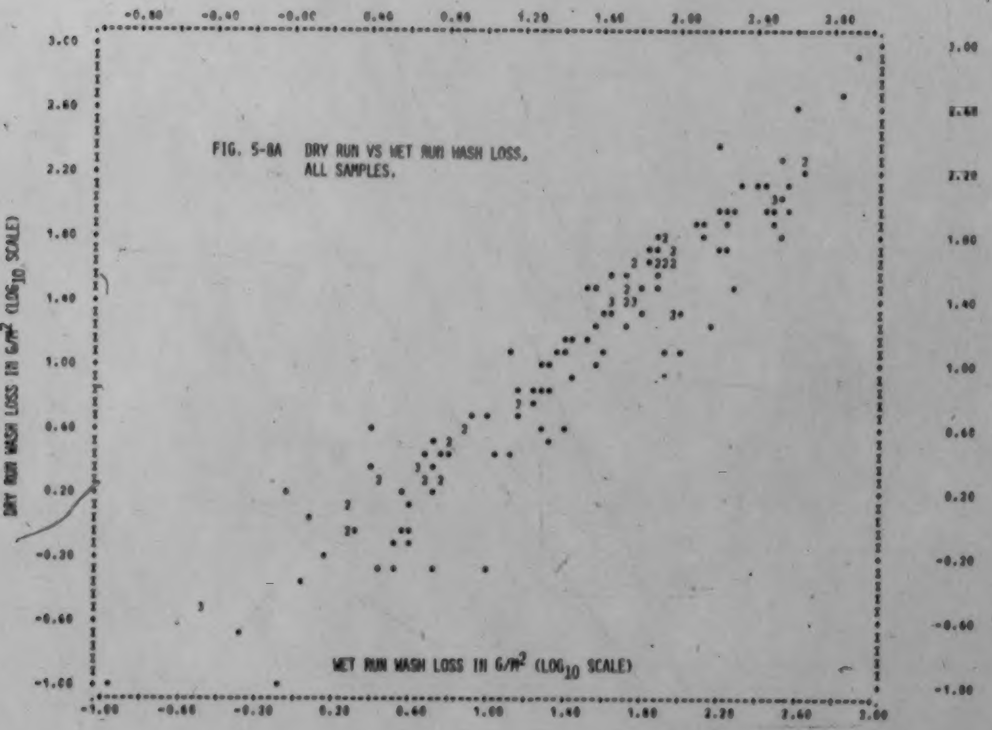


FIG. 5-8A DRY RUN VS WET RUN WASH LOSS, ALL SAMPLES.

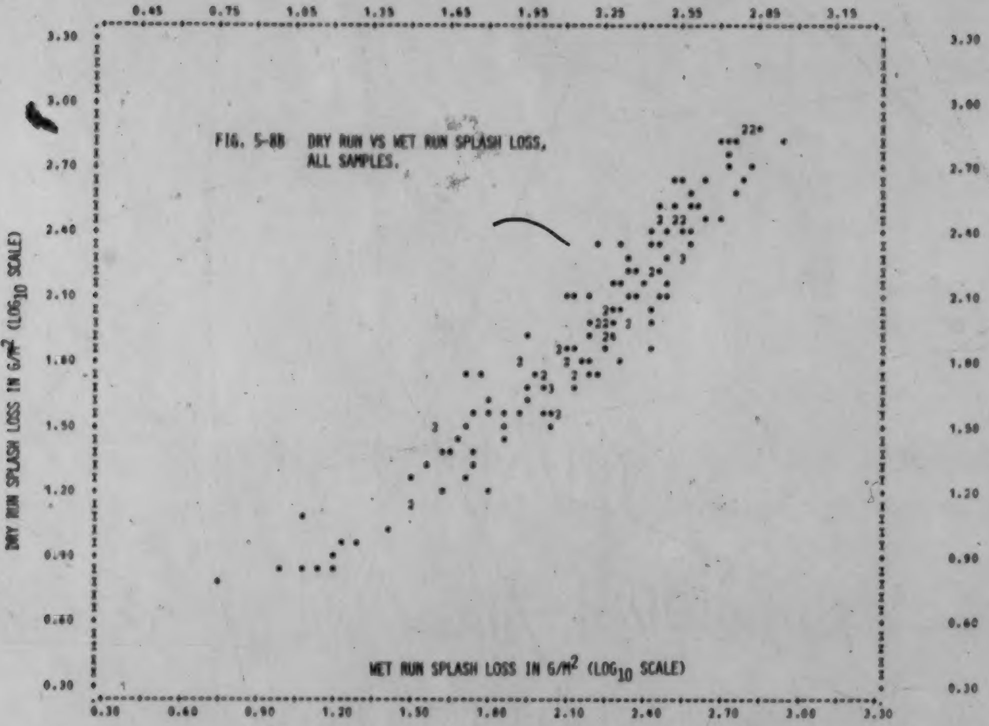


FIG. 5-8B DRY RUN VS WET RUN SPLASH LOSS, ALL SAMPLES.

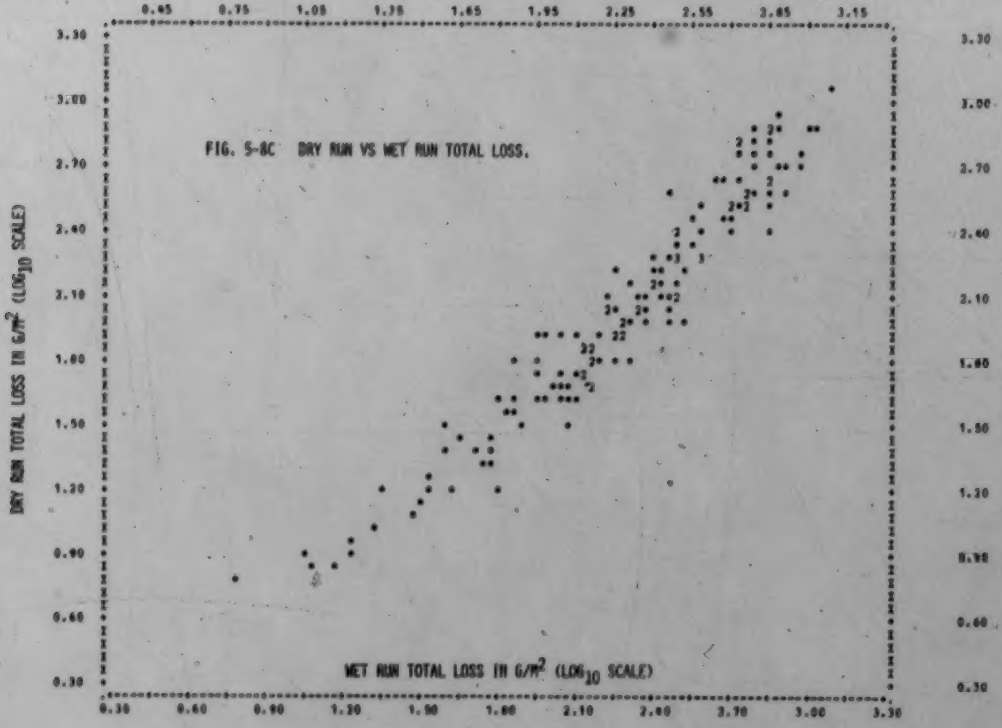


FIG. 5-8C DRY RUN VS WET RUN TOTAL LOSS.

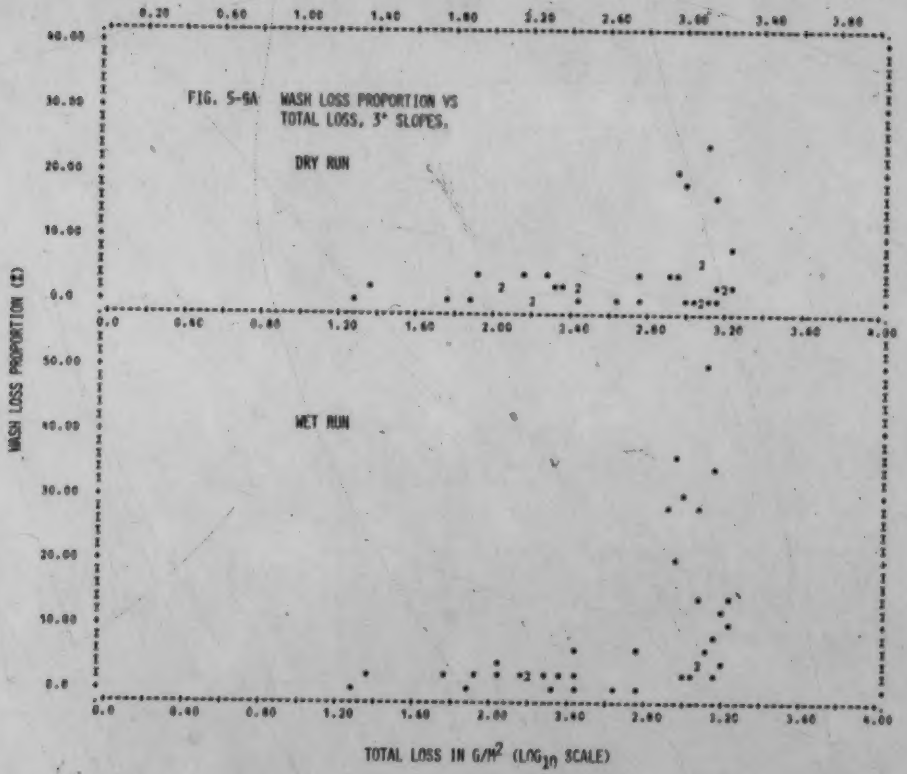


FIG. 5-9A WASH LOSS PROPORTION VS TOTAL LOSS, 3° SLOPES.

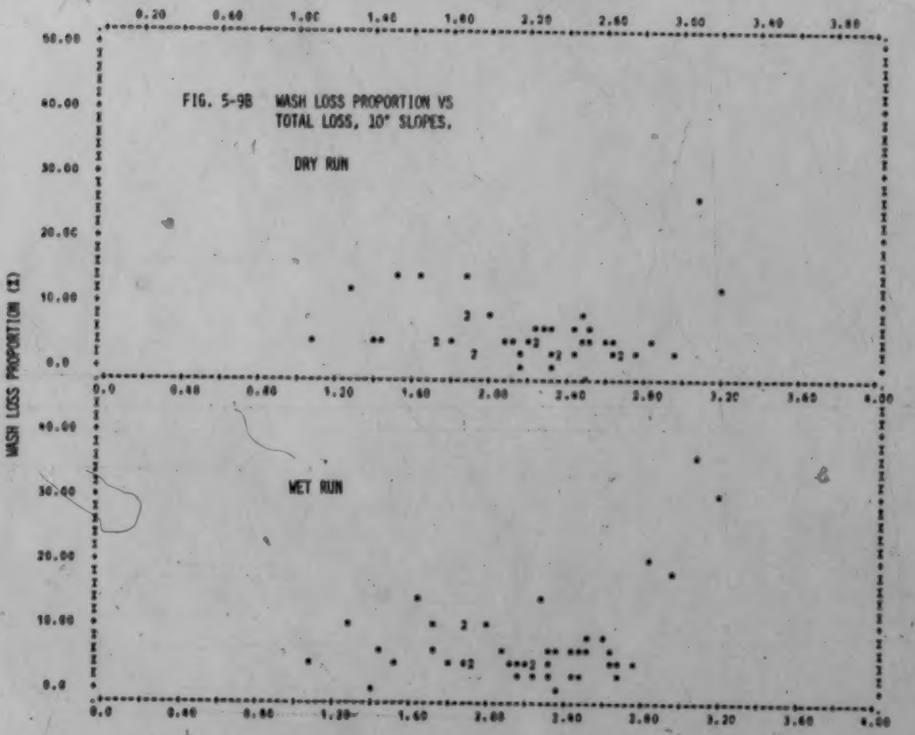


FIG. 5-9B WASH LOSS PROPORTION VS TOTAL LOSS, 10° SLOPES.

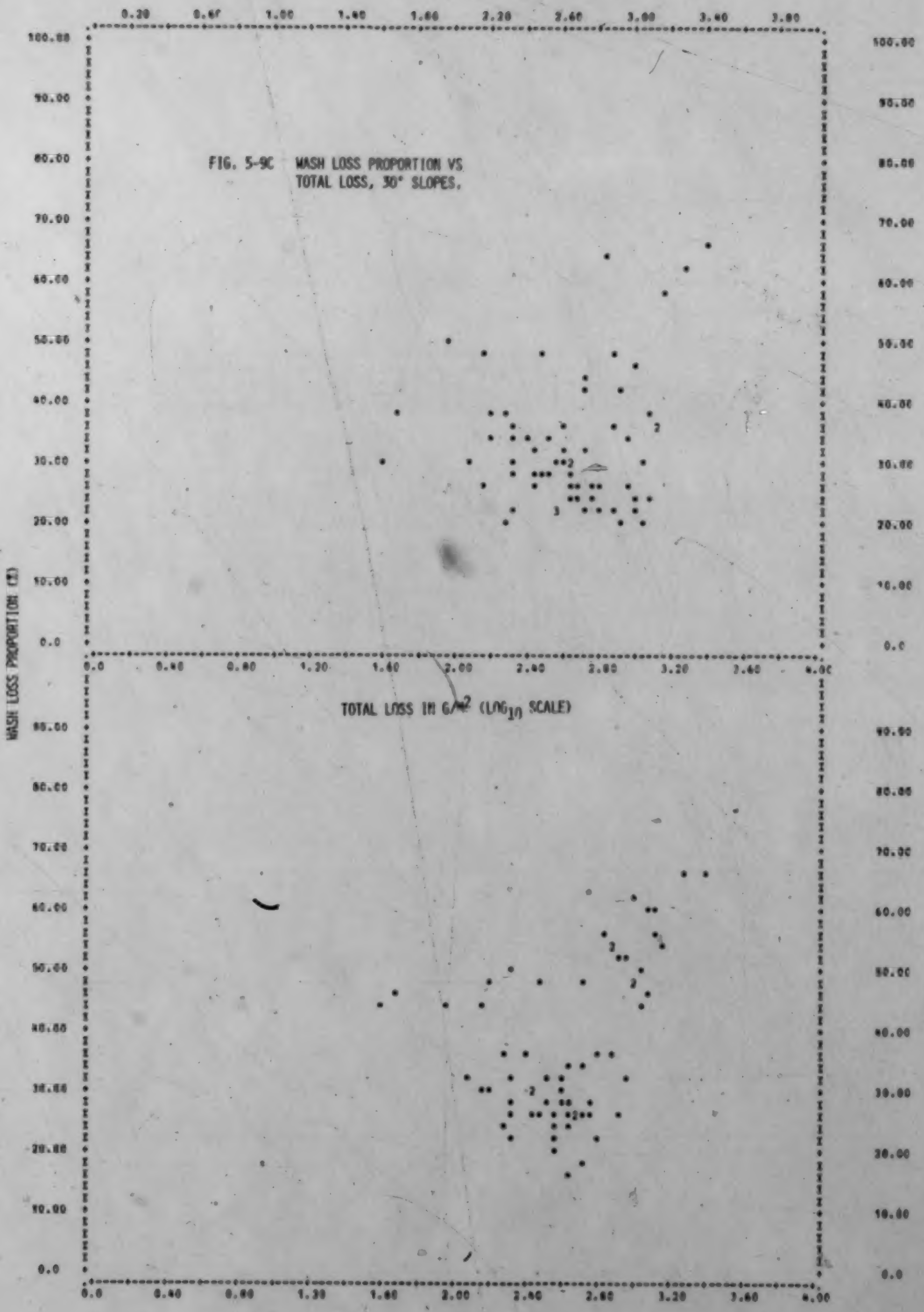


FIG. 5-9C WASH LOSS PROPORTION VS TOTAL LOSS, 30° SLOPES.

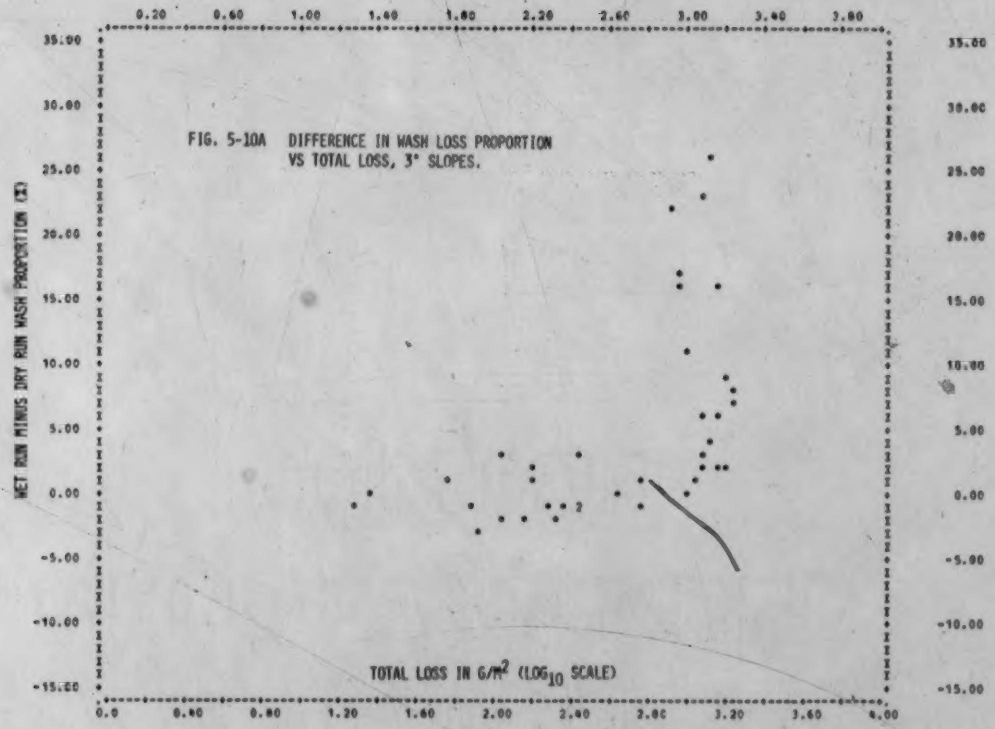


FIG. 5-10A DIFFERENCE IN WASH LOSS PROPORTION VS TOTAL LOSS, 3° SLOPES.

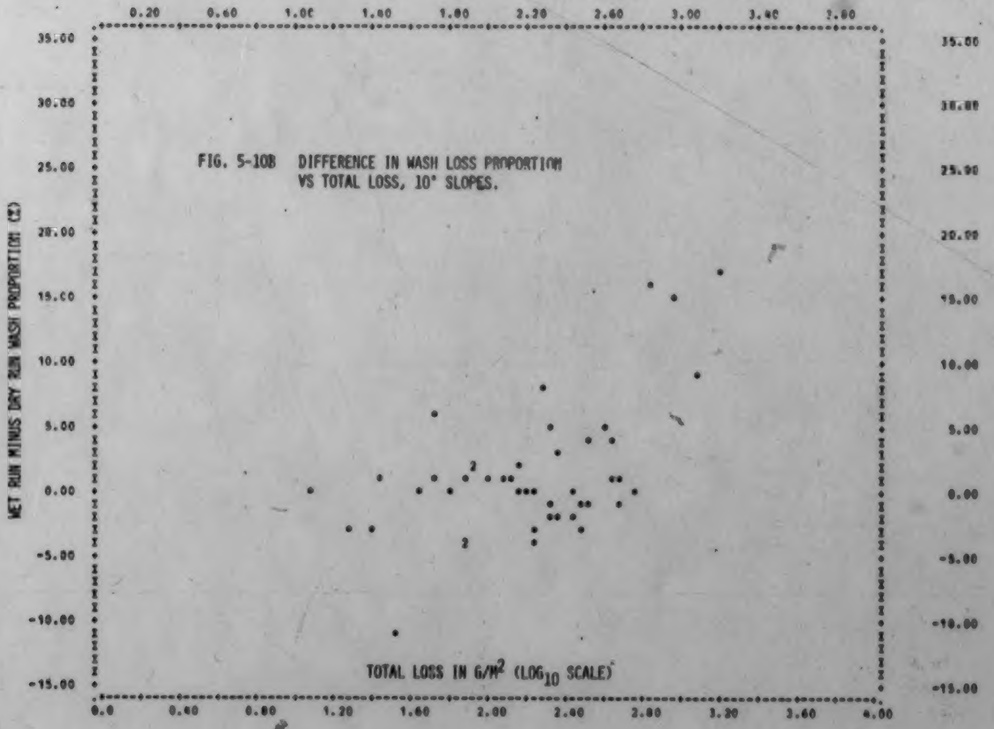


FIG. 5-10B DIFFERENCE IN WASH LOSS PROPORTION VS TOTAL LOSS, 10° SLOPES.

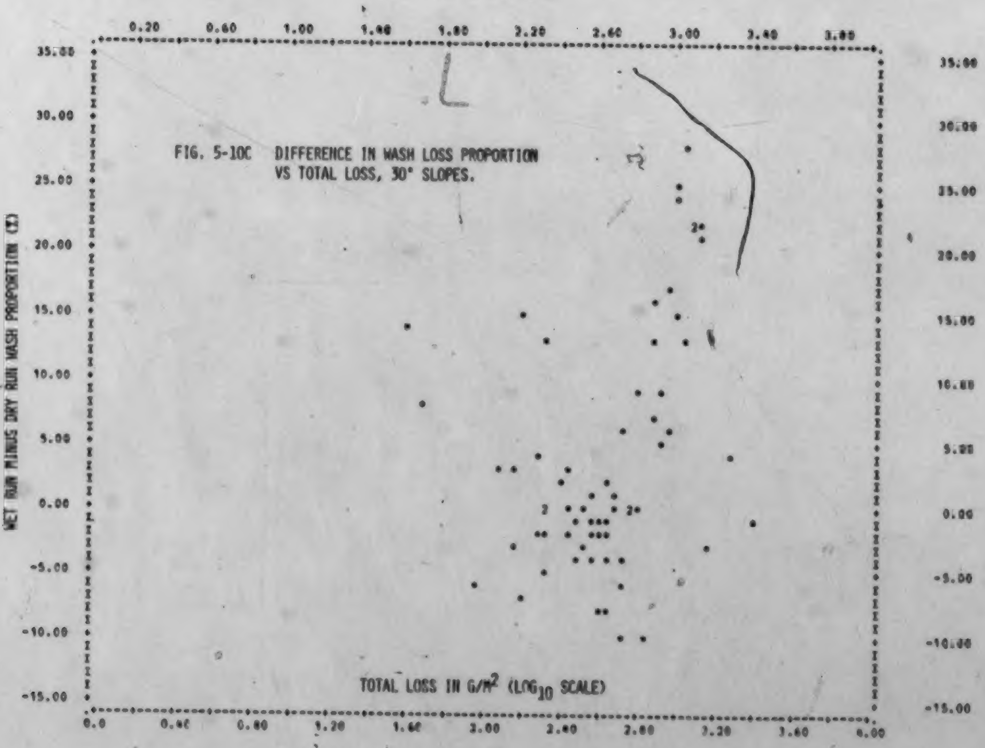
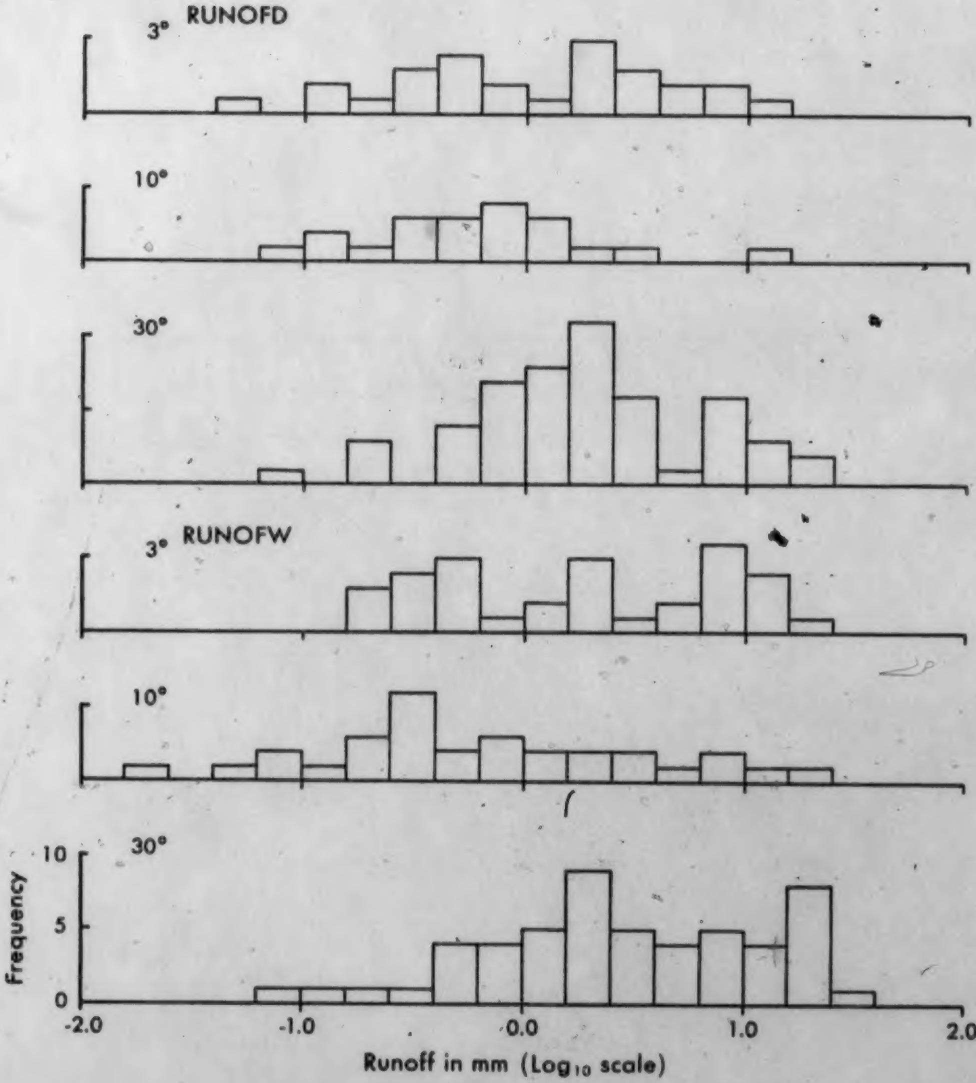


FIG. 5-10C DIFFERENCE IN WASH LOSS PROPORTION VS TOTAL LOSS, 30° SLOPES.

Figure 5-11

Frequency distribution of transformed runoff variables



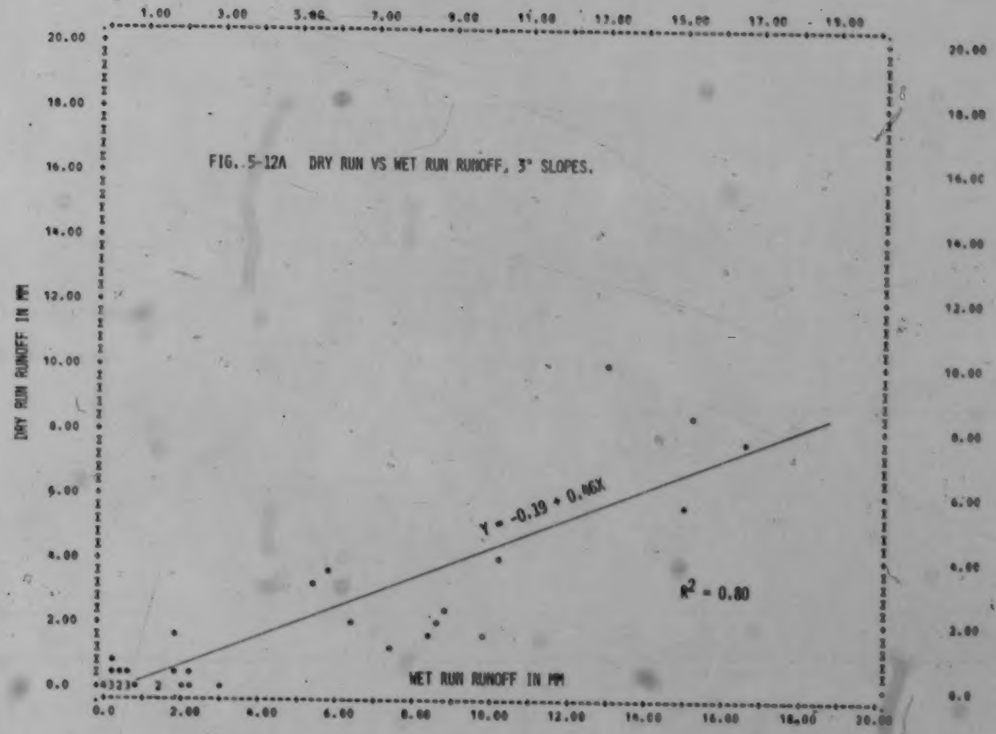


FIG. 5-12A DRY RUN VS WET RUN RUNOFF, 3° SLOPES.

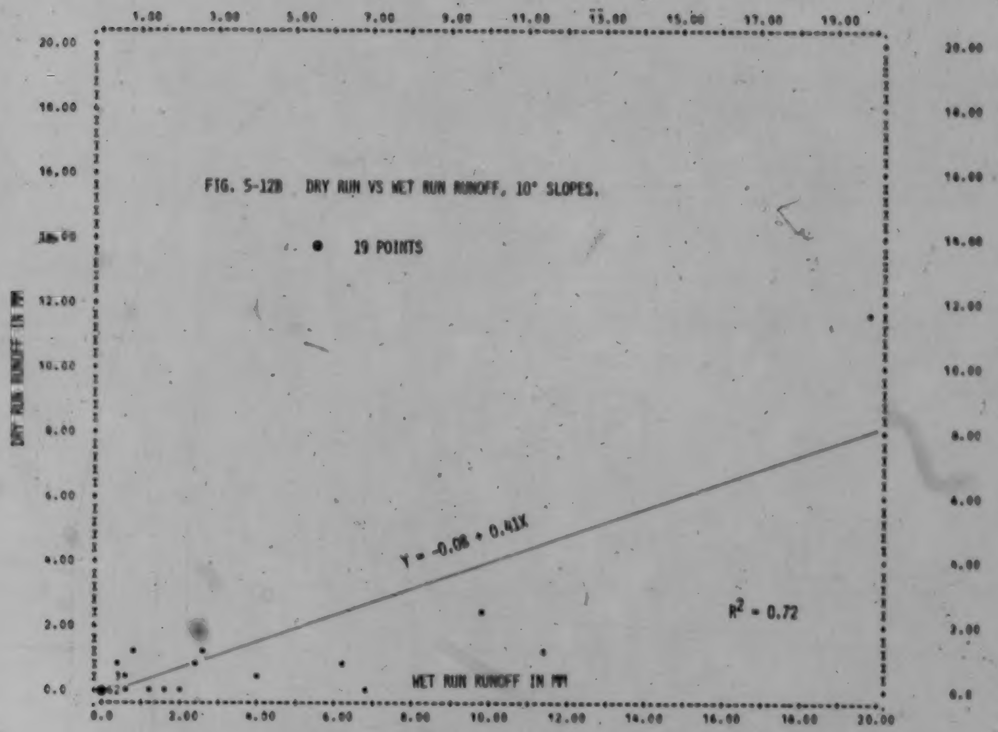


FIG. 5-12B DRY RUN VS WET RUN RUNOFF, 10° SLOPES.

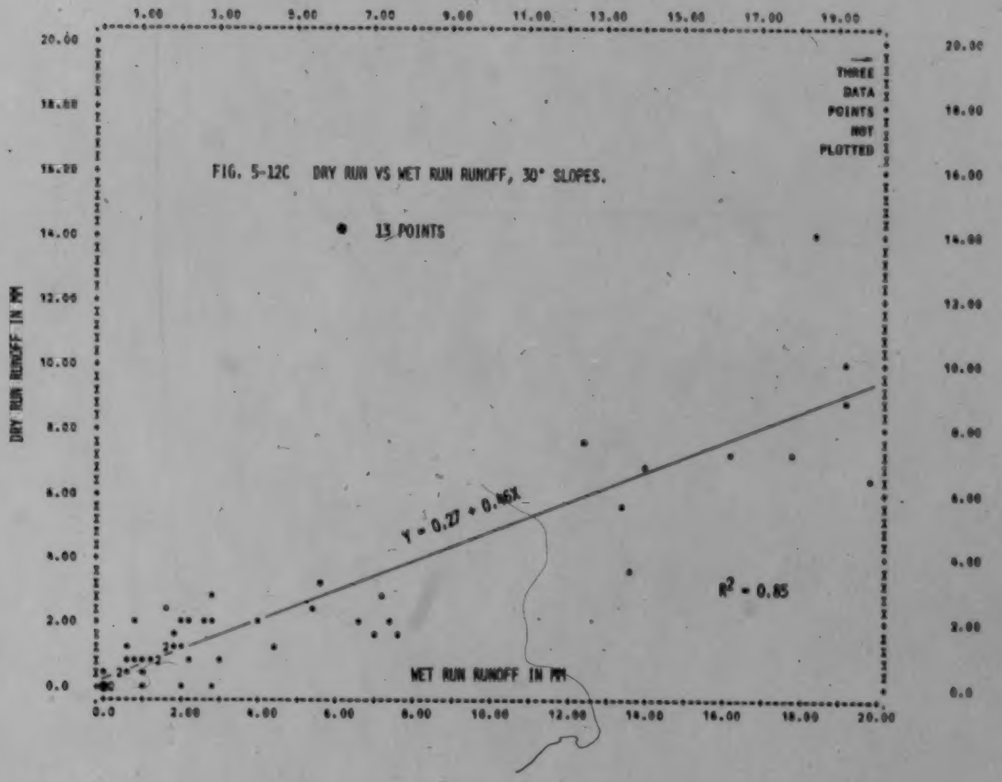


FIG. 5-12C DRY RUN VS WET RUN RUNOFF, 30° SLOPES.

Figure 5-13
Runoff rates of six selected samples

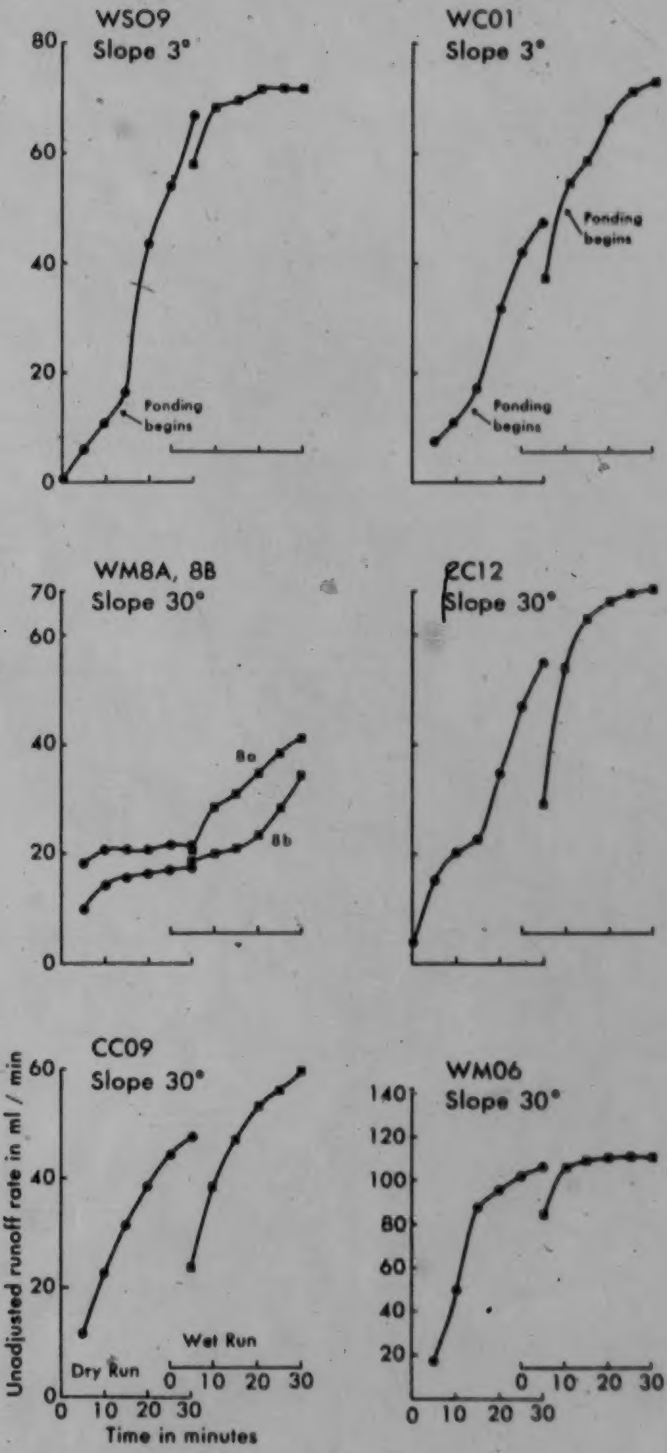
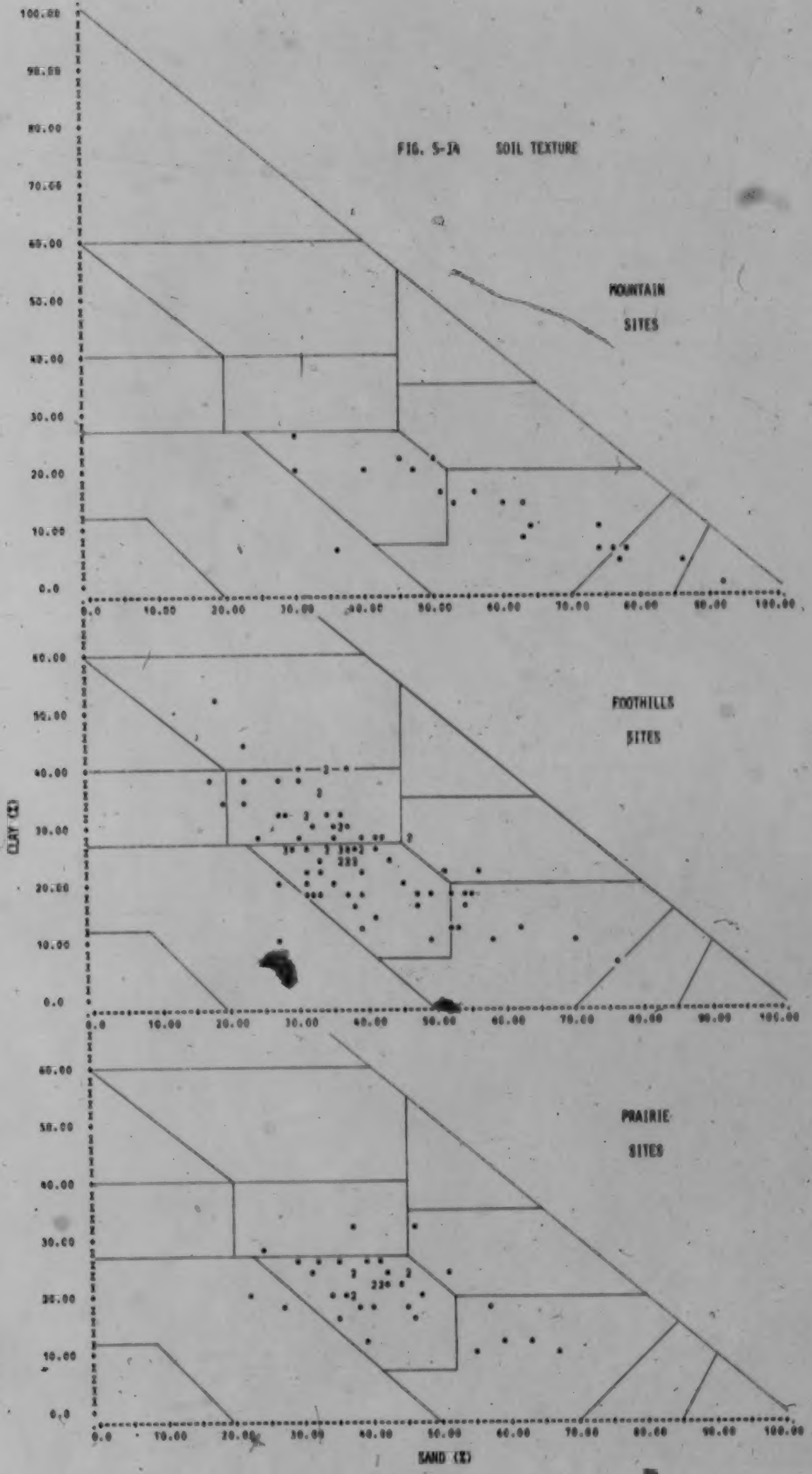


FIG. 5-IA SOIL TEXTURE



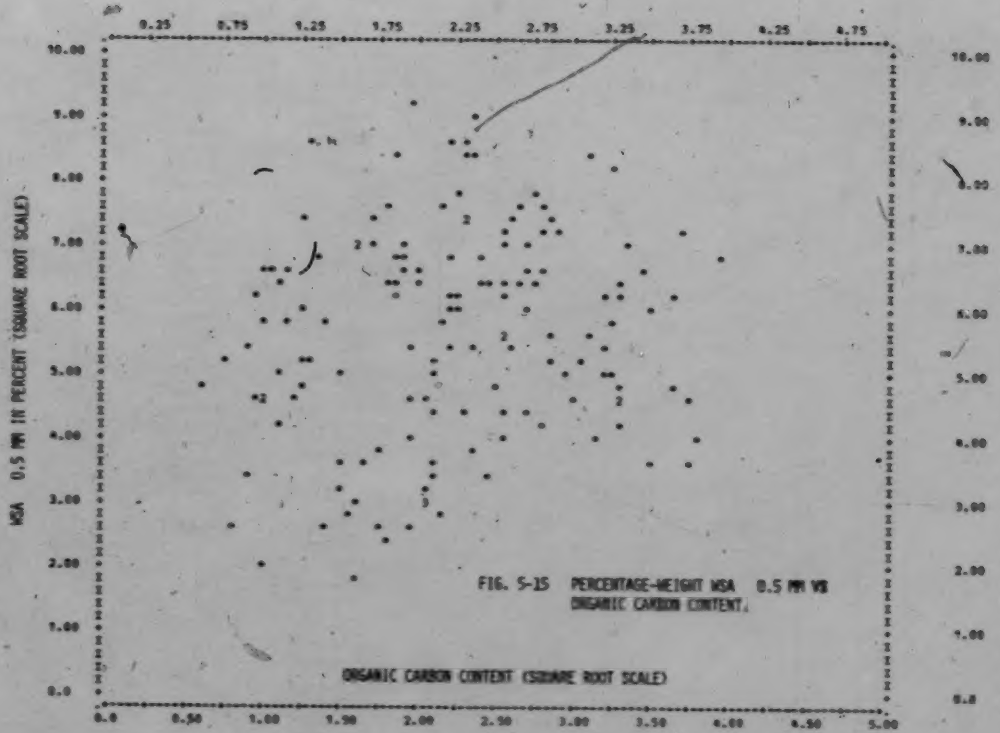
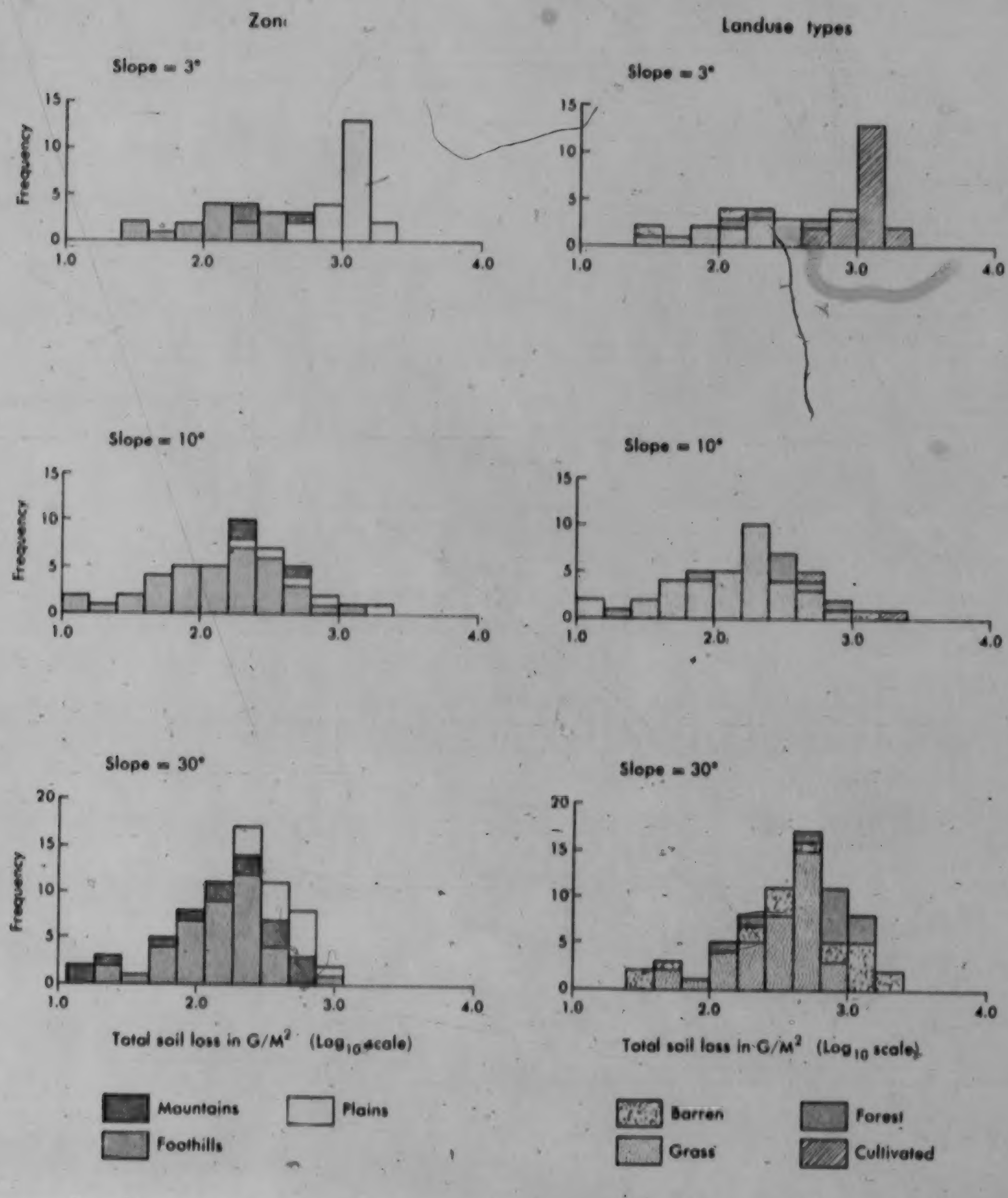


FIG. 5-15 PERCENTAGE-WEIGHT MSA 0.5 MM VS ORGANIC CARBON CONTENT.

Figure 6-1
Classification of total soil loss by zone and landuse types



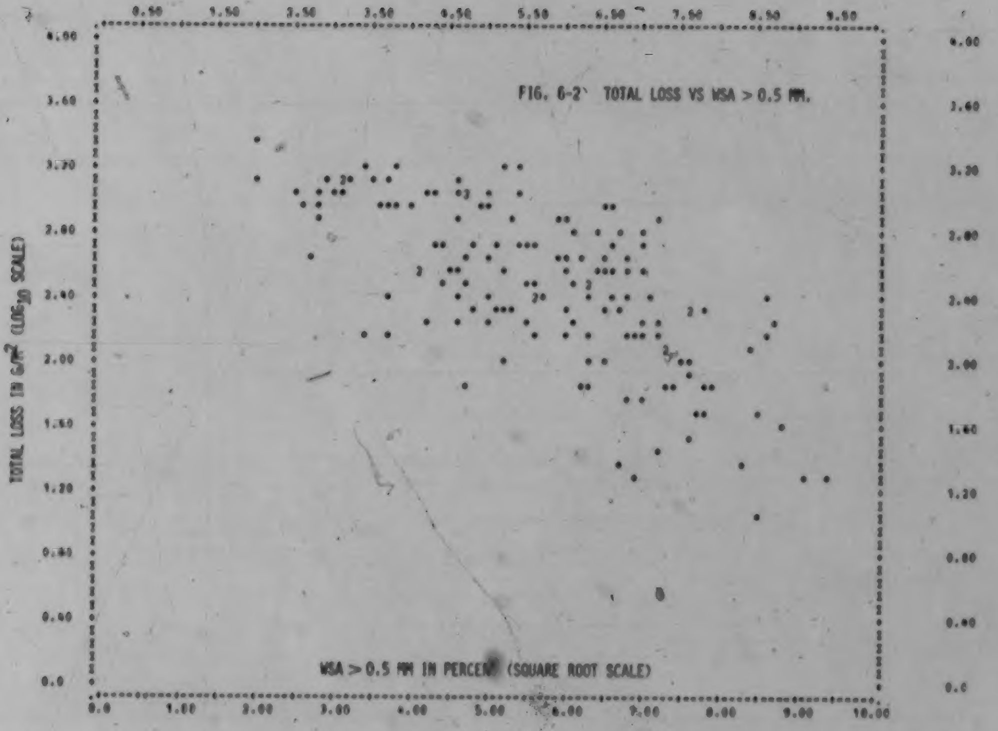


FIG. 6-2 TOTAL LOSS VS WSA > 0.5 MM.

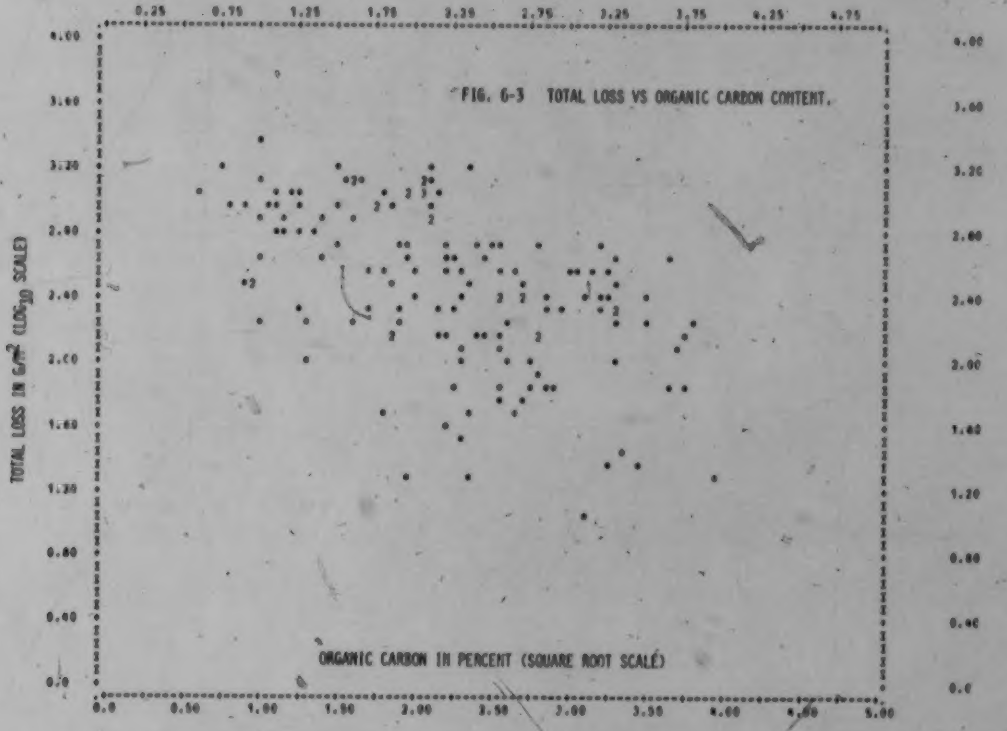


FIG. 6-3 TOTAL LOSS VS ORGANIC CARBON CONTENT.

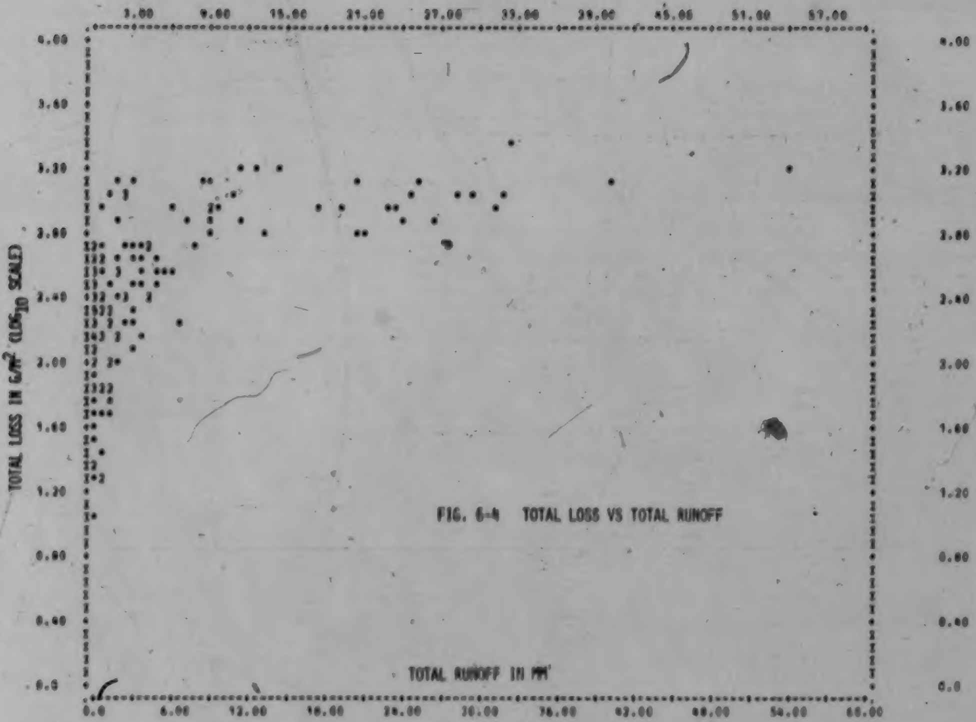


FIG. 6-4 TOTAL LOSS VS TOTAL RUNOFF

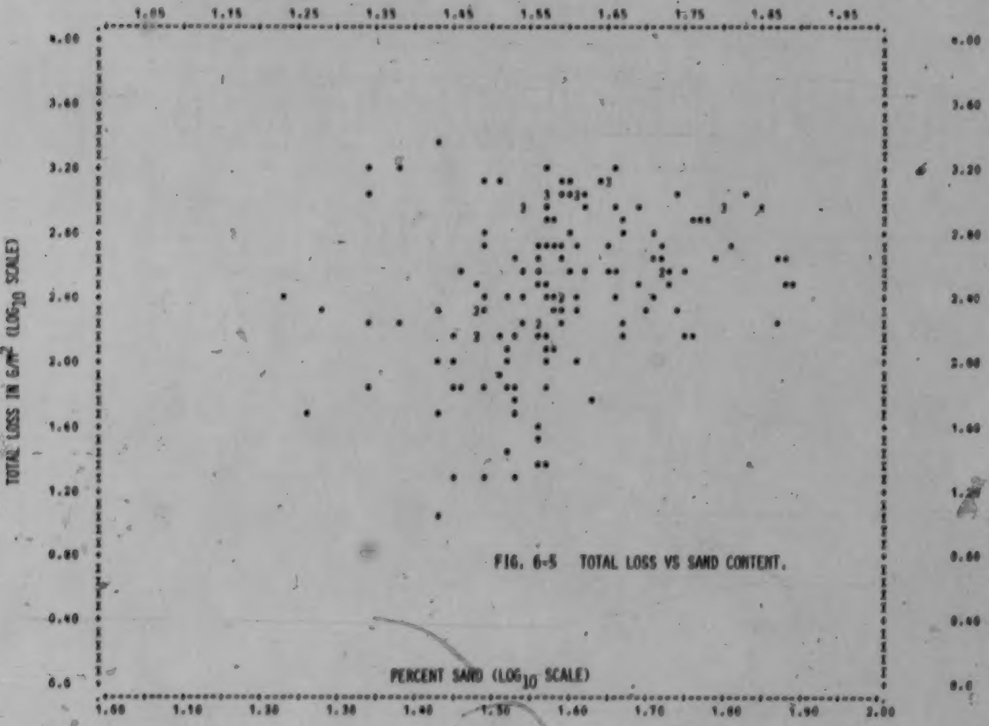


FIG. 6-5 TOTAL LOSS VS SAND CONTENT.

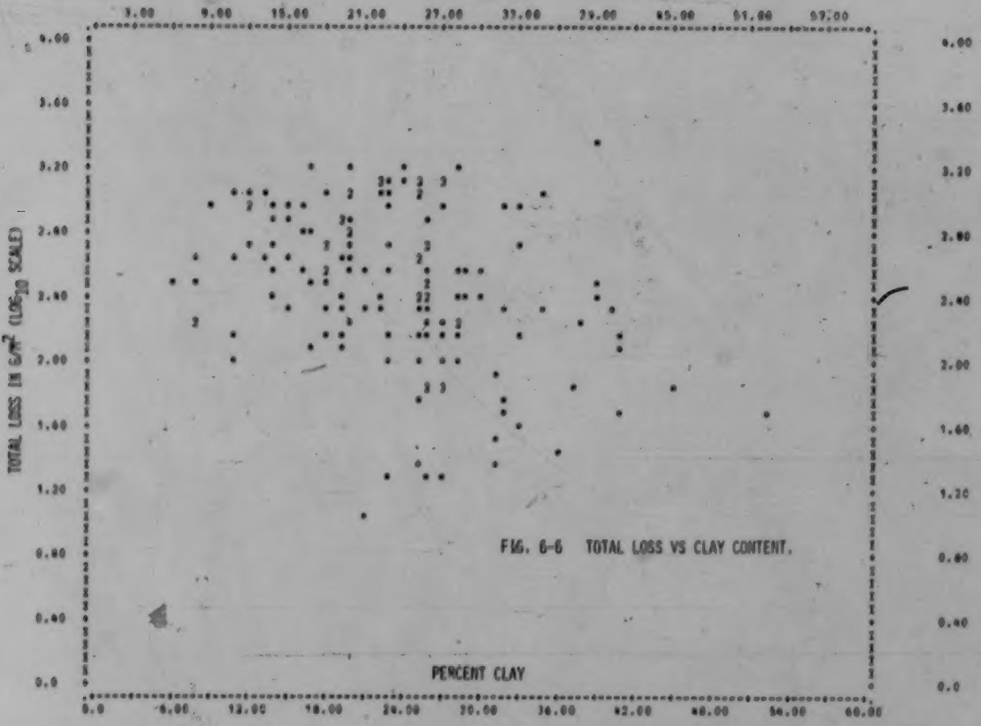


FIG. 6-6 TOTAL LOSS VS CLAY CONTENT.

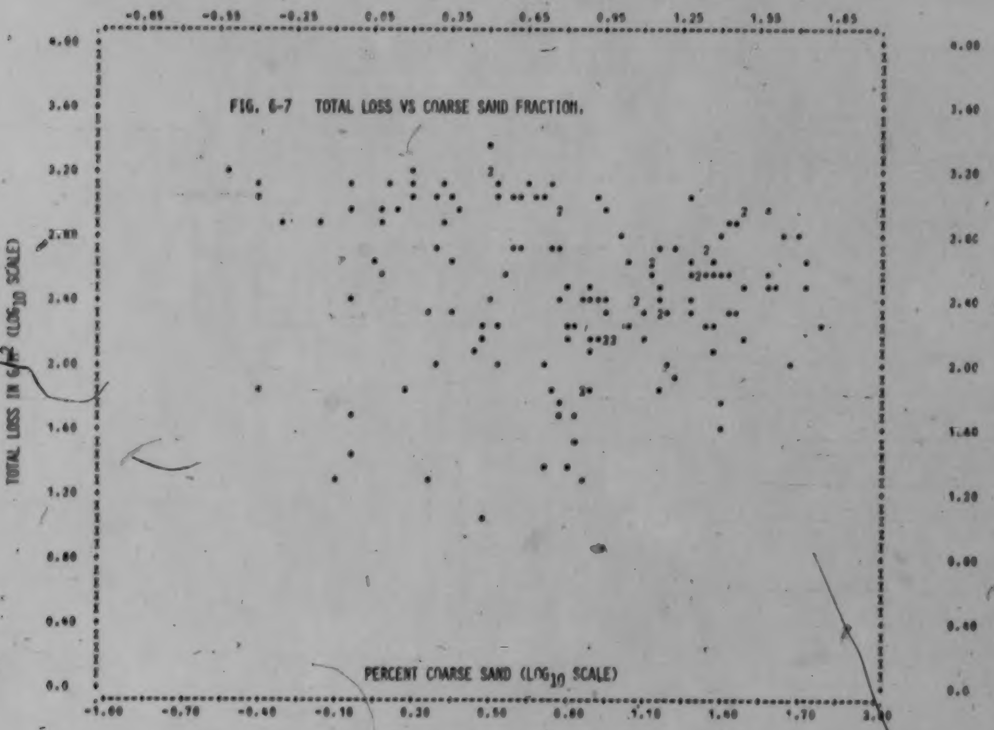


FIG. 6-7 TOTAL LOSS VS COARSE SAND FRACTION.

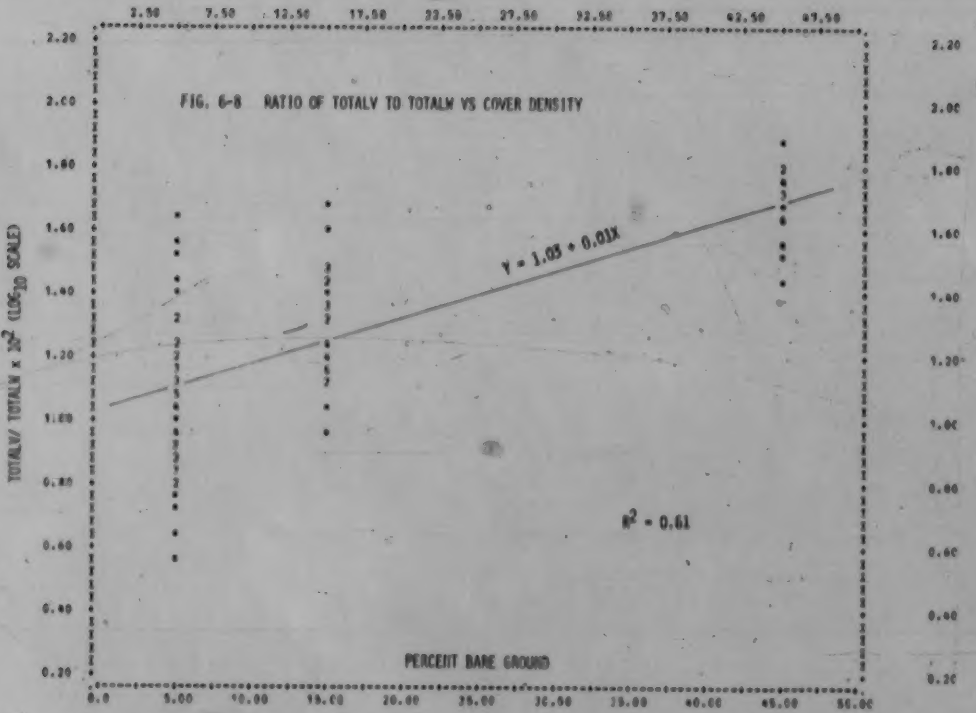


FIG. 6-8 RATIO OF TOTALV TO TOTALW VS COVER DENSITY

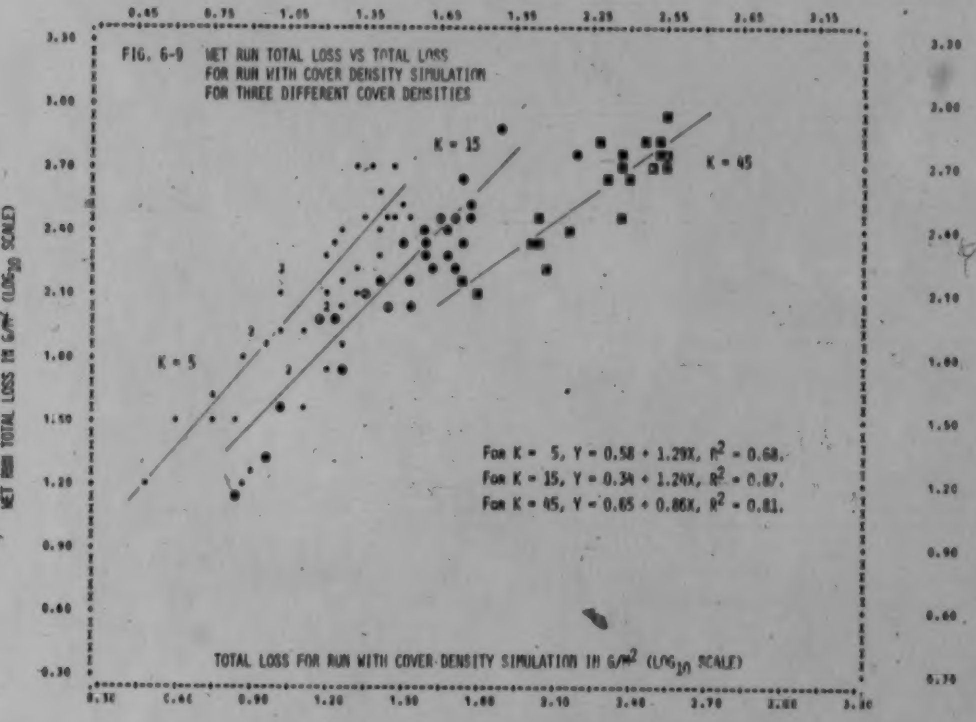


FIG. 6-9 WET RUN TOTAL LOSS VS TOTAL LOSS
FOR RUN WITH COVER DENSITY SIMULATION
FOR THREE DIFFERENT COVER DENSITIES

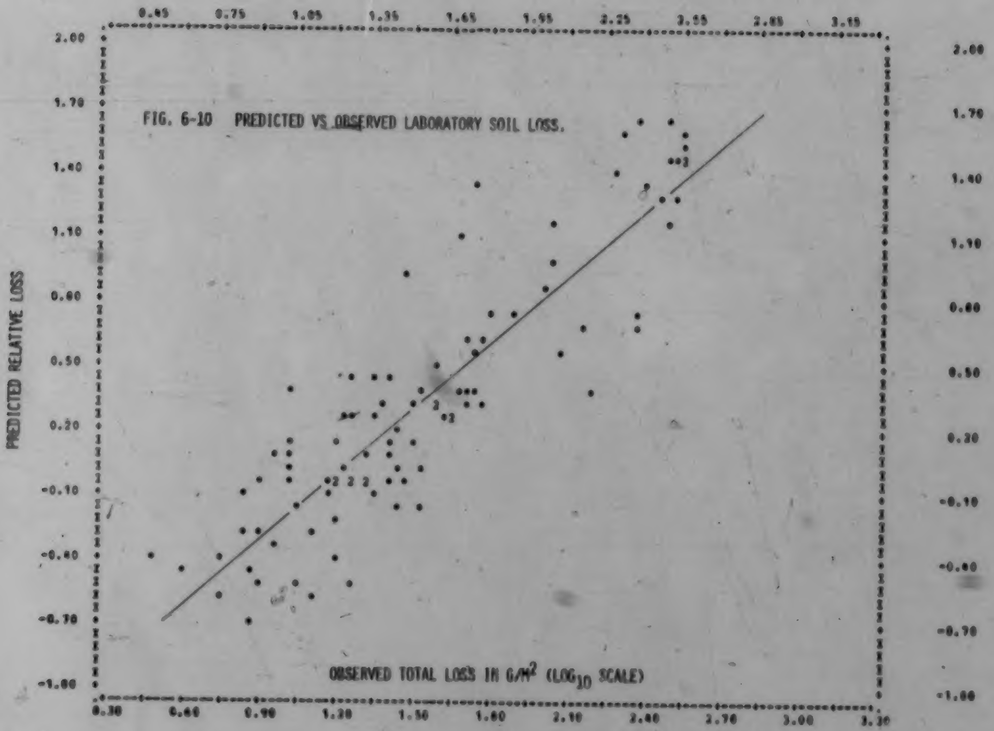


FIG. 6-10 PREDICTED VS OBSERVED LABORATORY SOIL LOSS.

FIG. 6-11 STANDARDIZED RESIDUAL PLOT, PREDICTED VS OBSERVED SOIL LOSS.

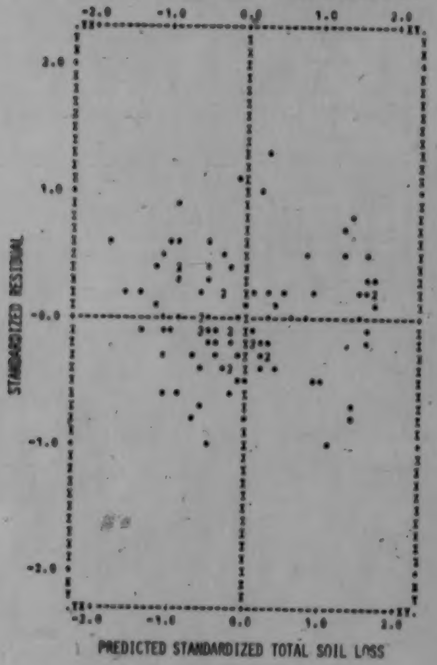


Figure 7-1

Relationship between frequency of hourly rainfall intensity exceeding 2.5 mm/hr and total rainfall amount, Station Calgary A, May to August, 1961-1973

Data Source:
Monthly Records, Atmospheric Environment Service, Environment Canada

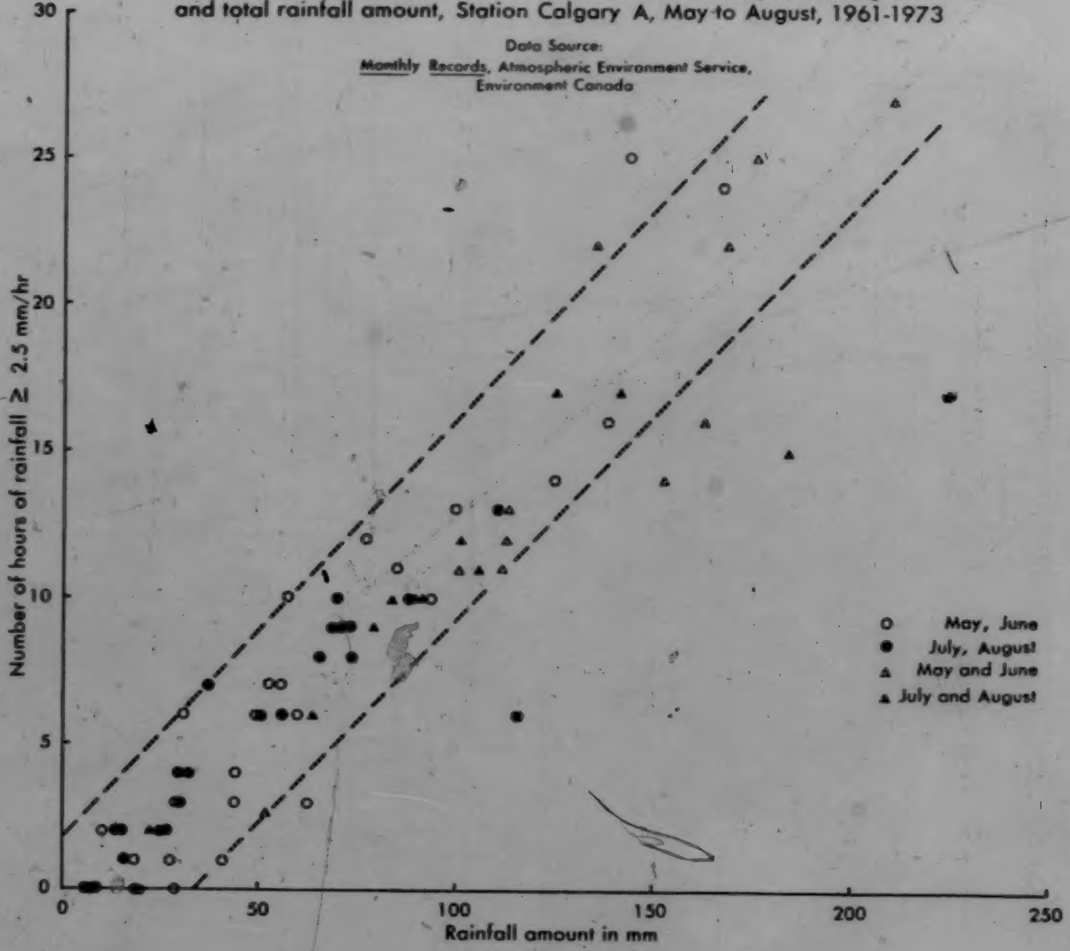
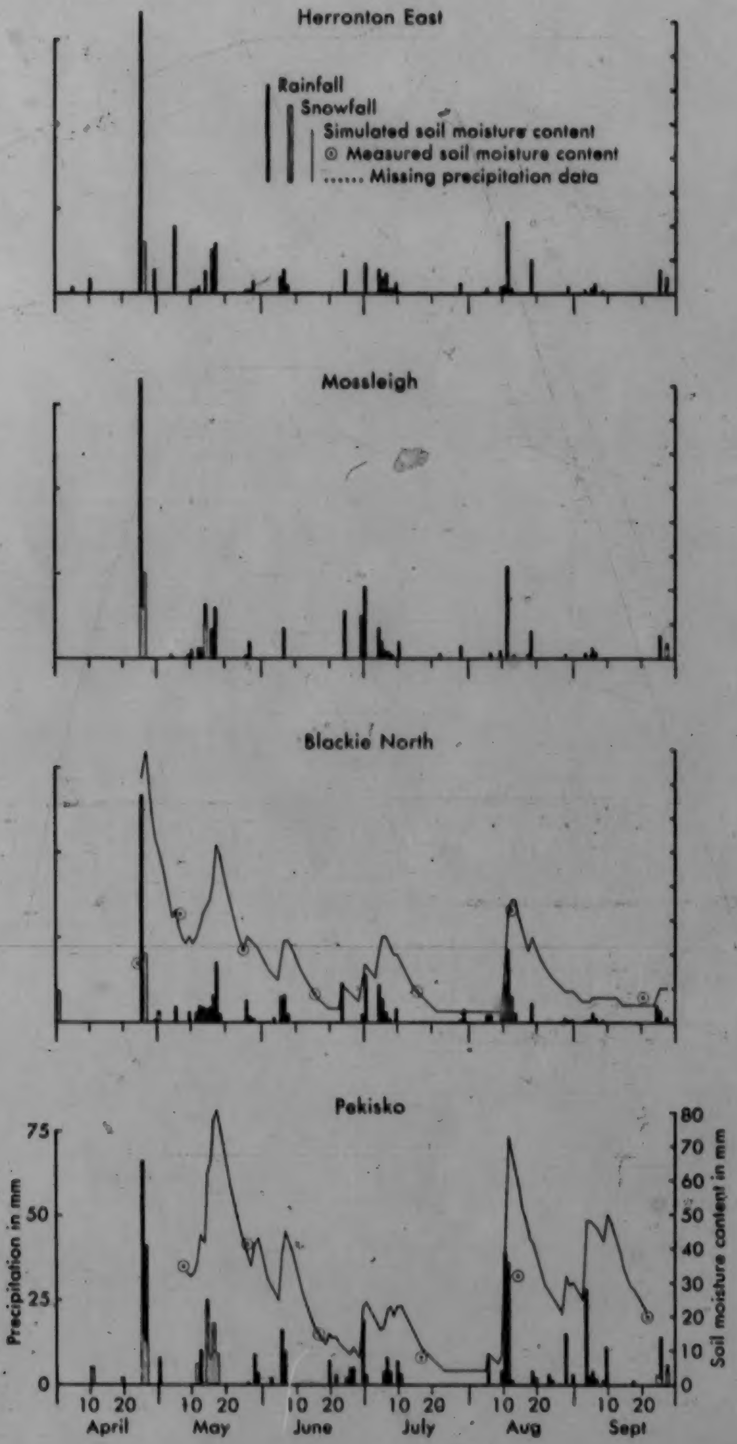


Figure 7-2

Precipitation and rainfall amounts for eight selected stations, April to September, 1974



Herronton East

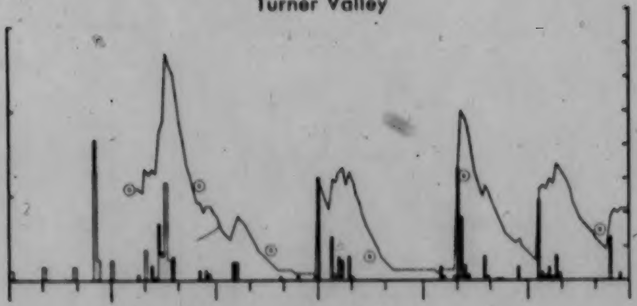
Mossleigh

Blackie North

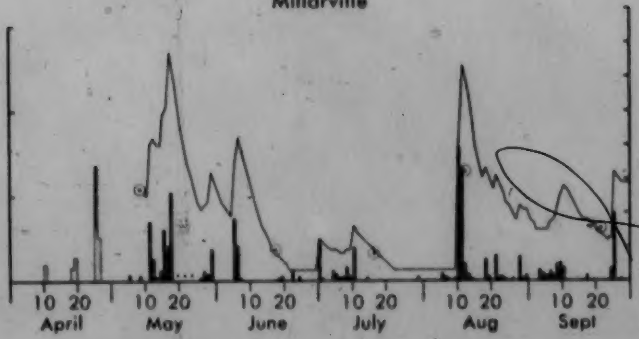
Pekisko

Figure 7-2 (cont.)

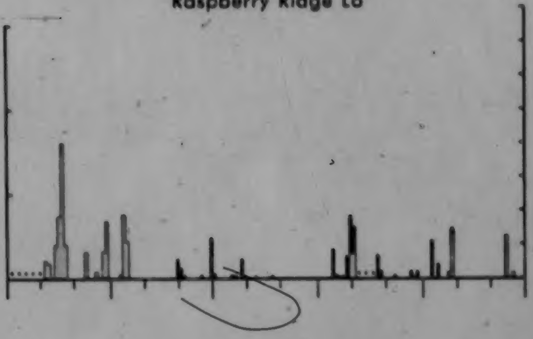
Turner Valley



Millarville



Raspberry Ridge Lo



Hailstone Butte Lo

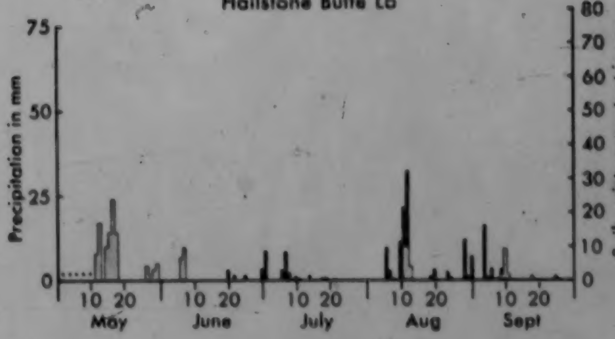


Figure 7-3
Cover density for selected sites April-September, 1974

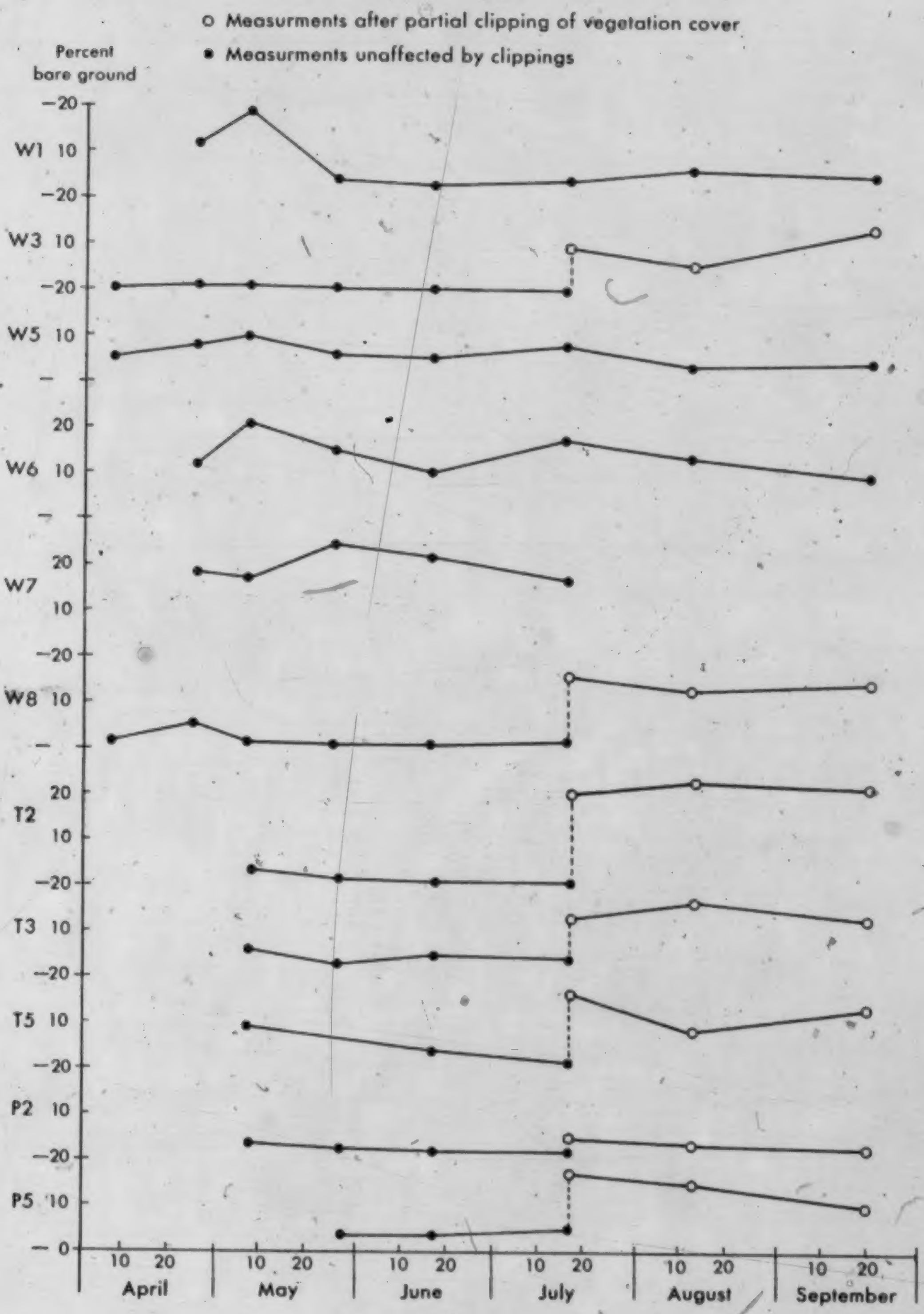
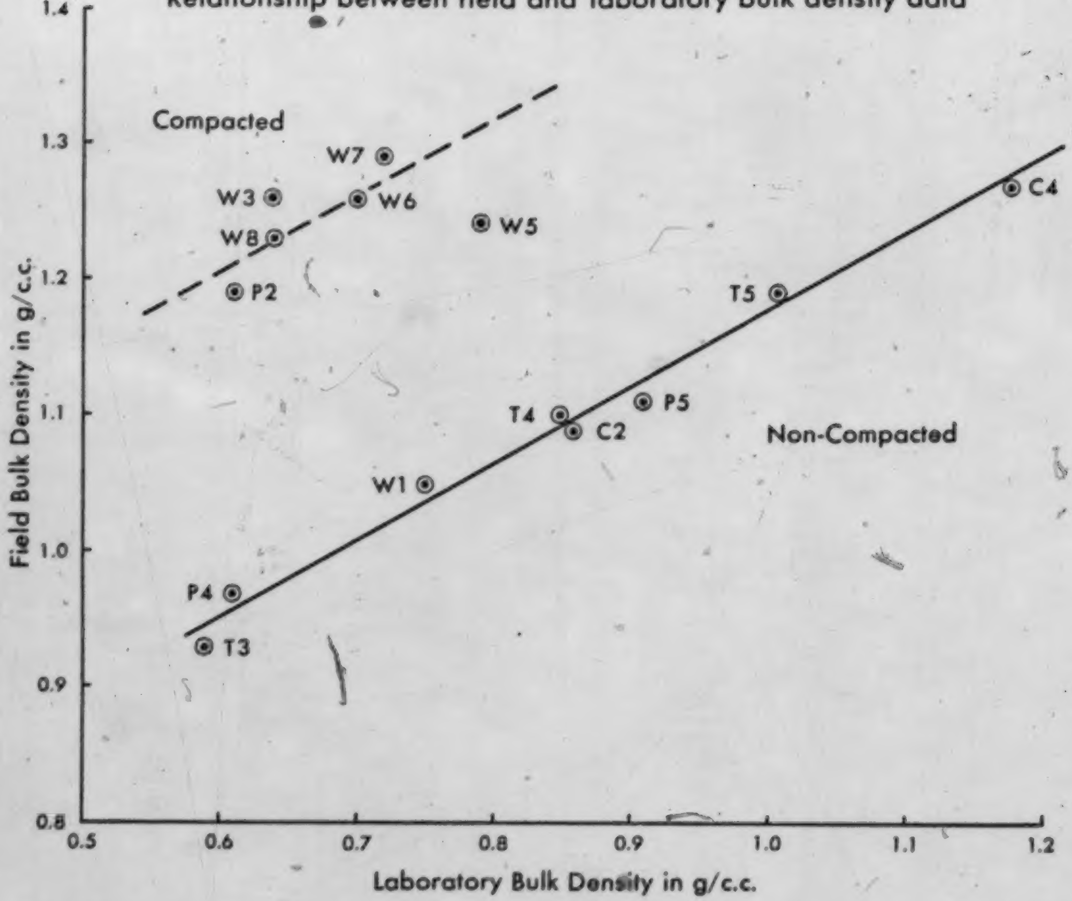


Figure 7-4

Relationship between field and laboratory bulk density data



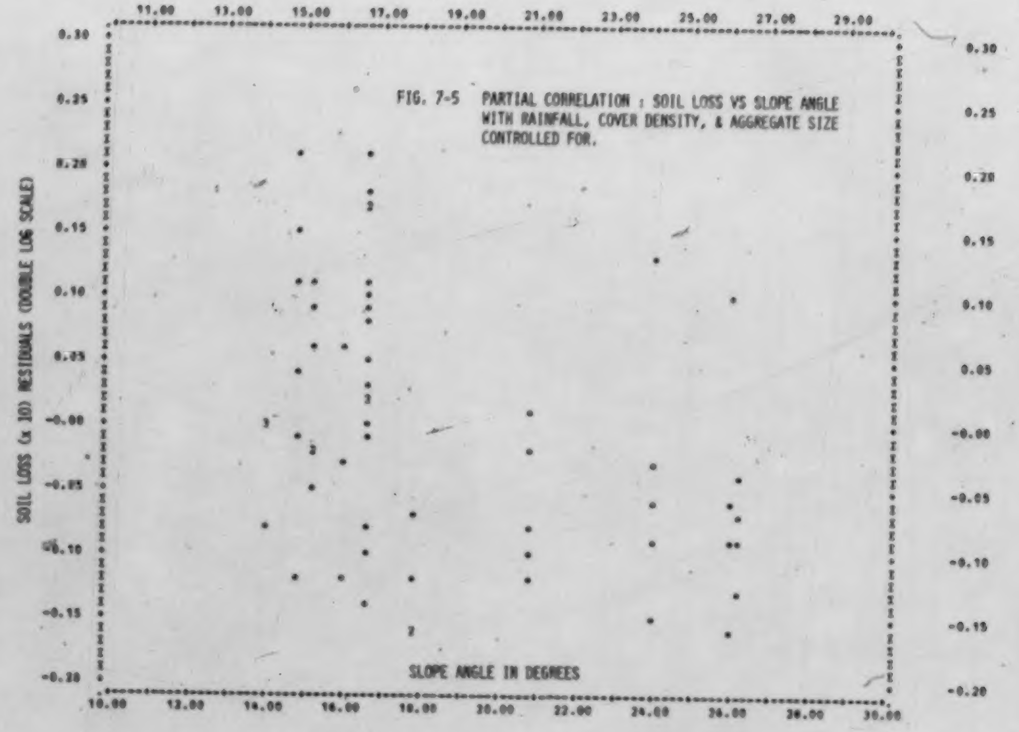
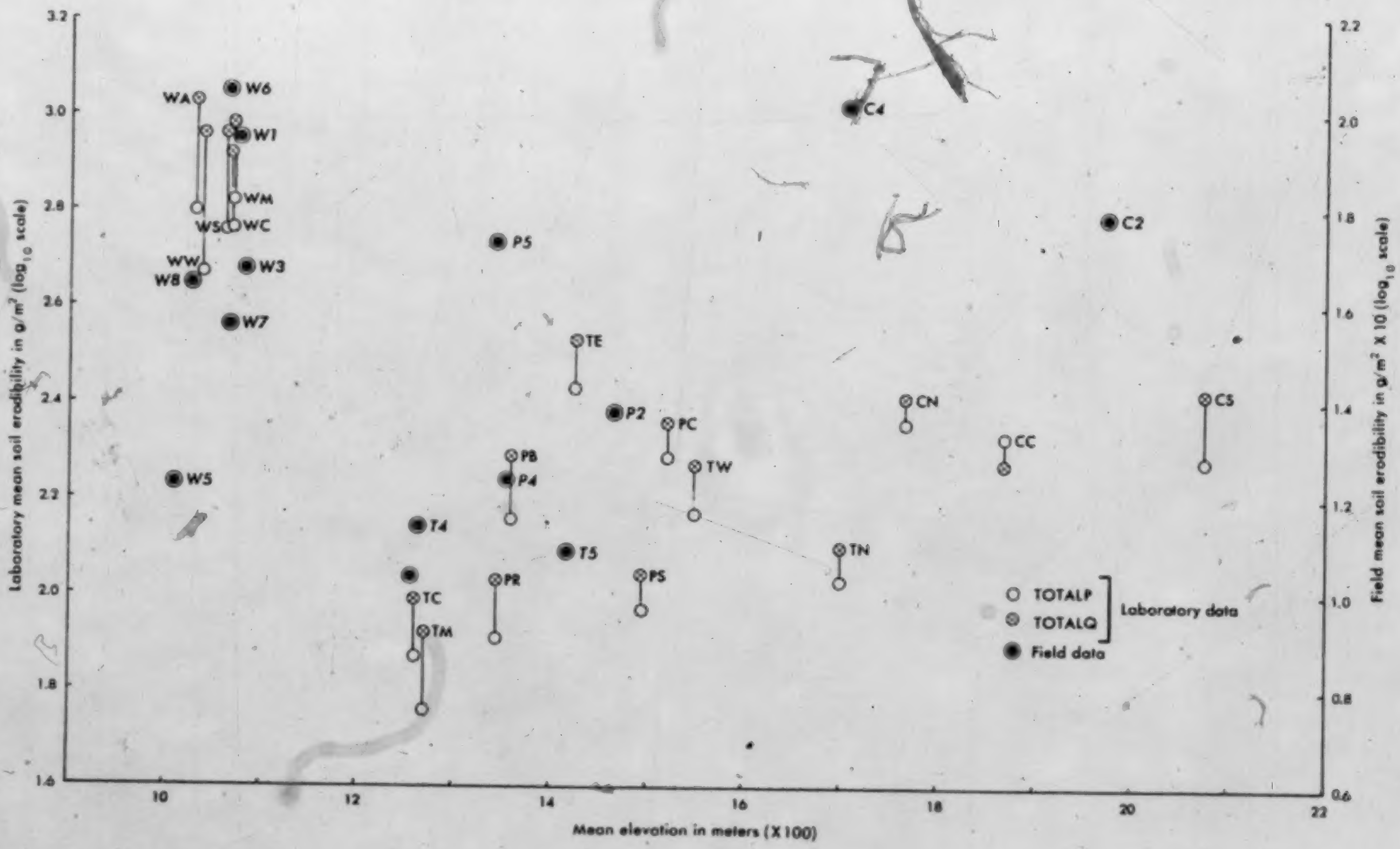


FIG. 7-5 PARTIAL CORRELATION : SOIL LOSS VS SLOPE ANGLE WITH RAINFALL, COVER DENSITY, & AGGREGATE SIZE CONTROLLED FOR.

Figure 8-1

Field and laboratory mean soil erodibility plotted against mean elevation



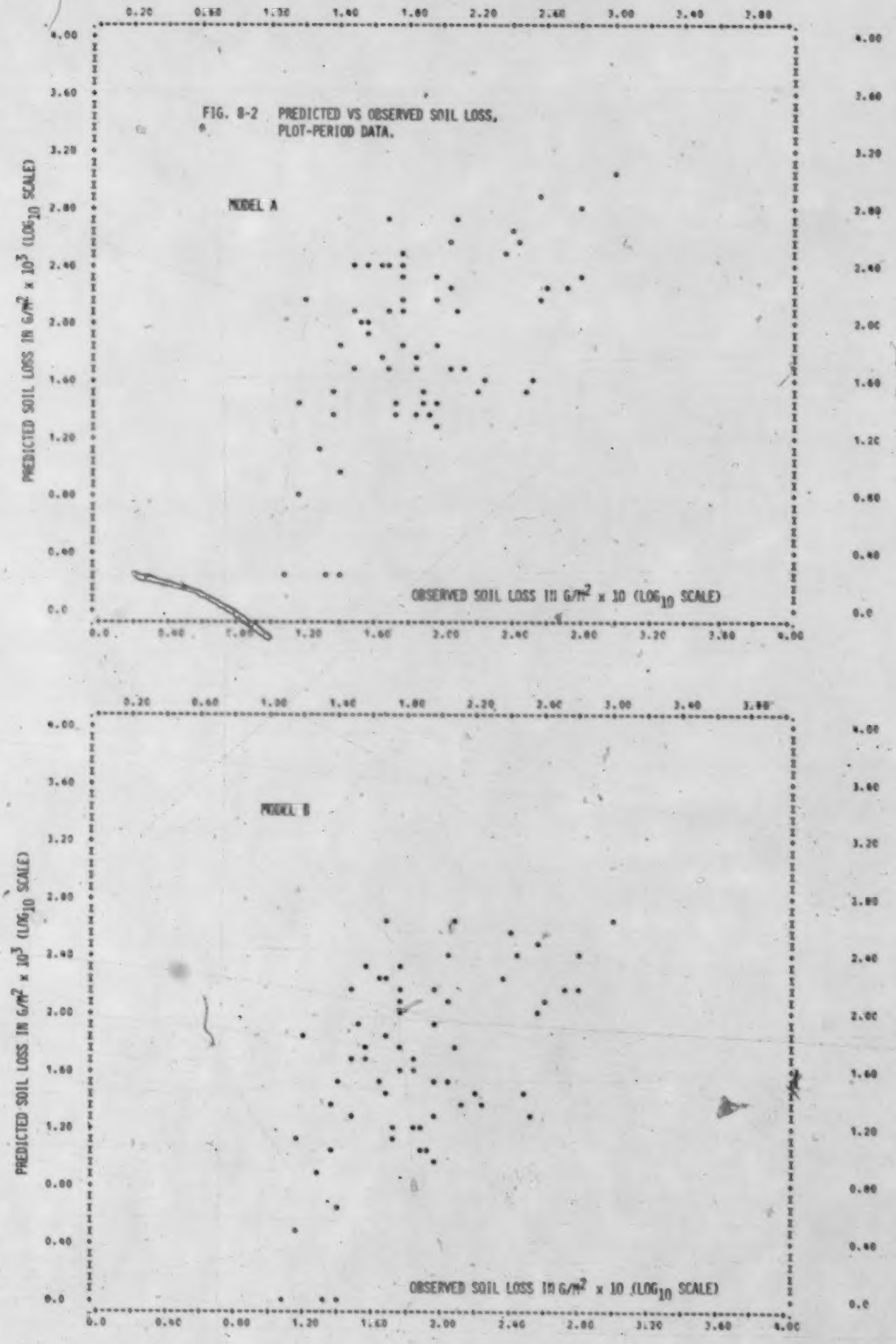


FIG. 8-2 PREDICTED VS OBSERVED SOIL LOSS, PLOT-PERIOD DATA.

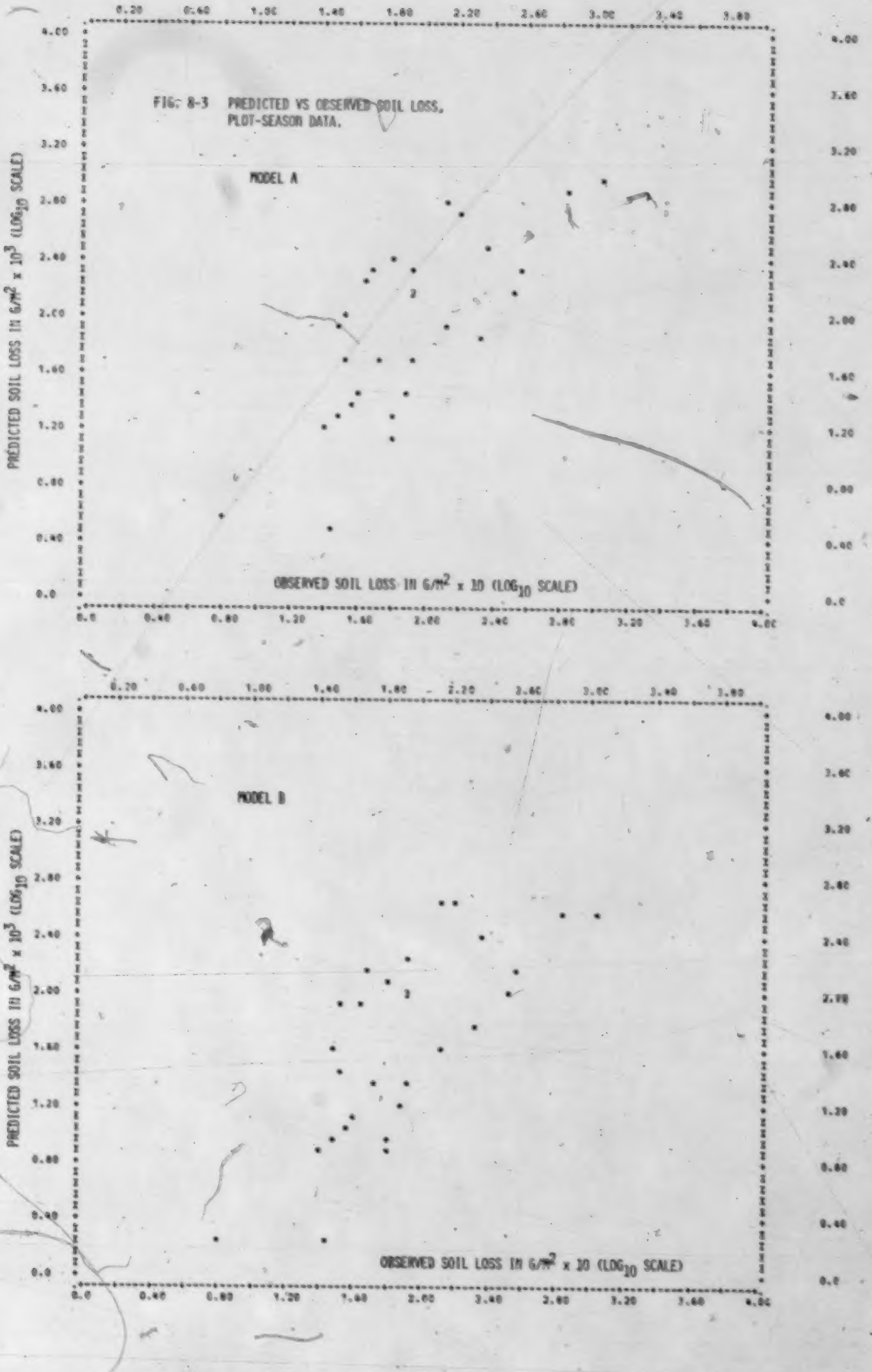


FIG. 8-3 PREDICTED VS OBSERVED SOIL LOSS, PLOT-SEASON DATA.

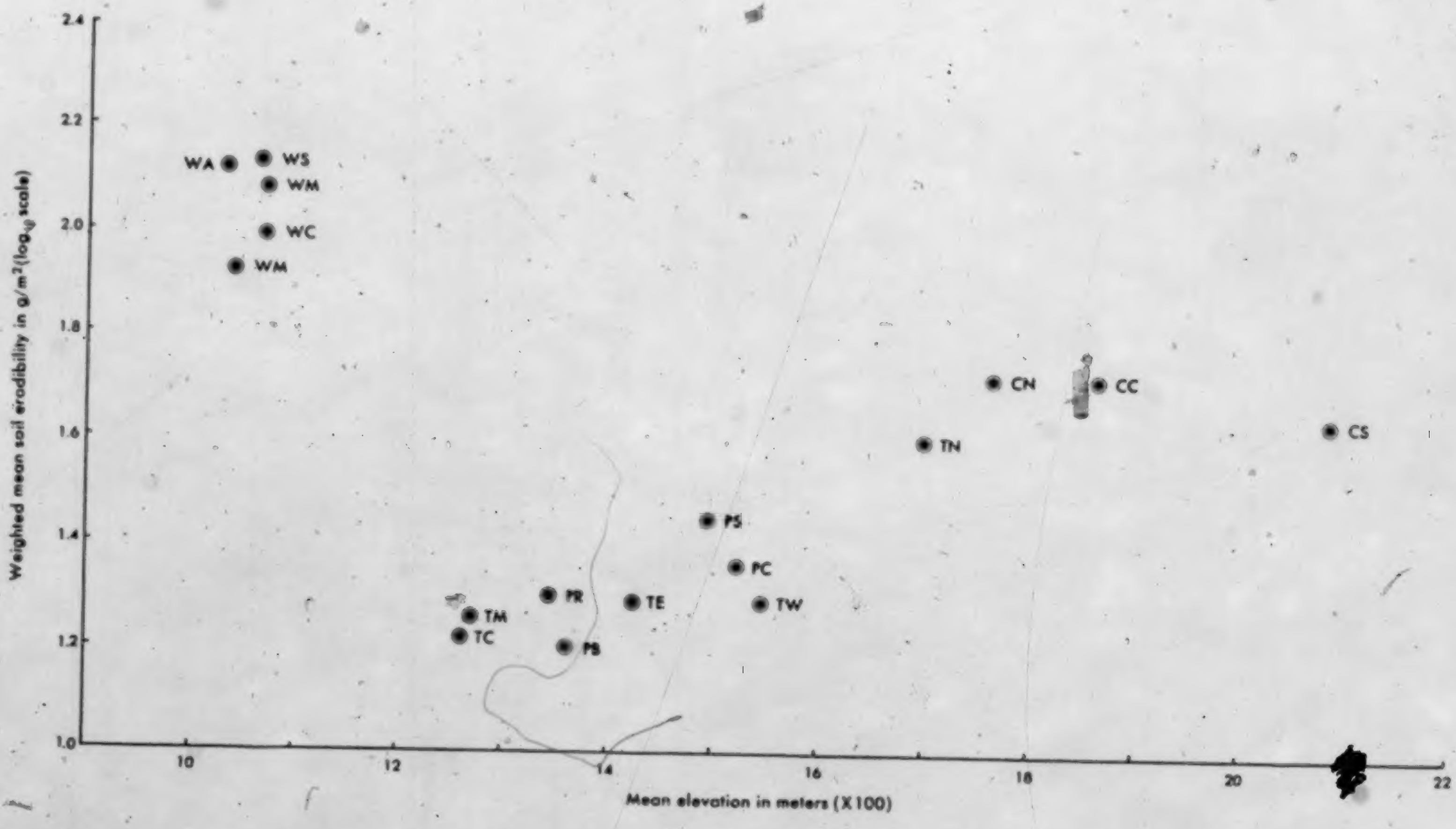
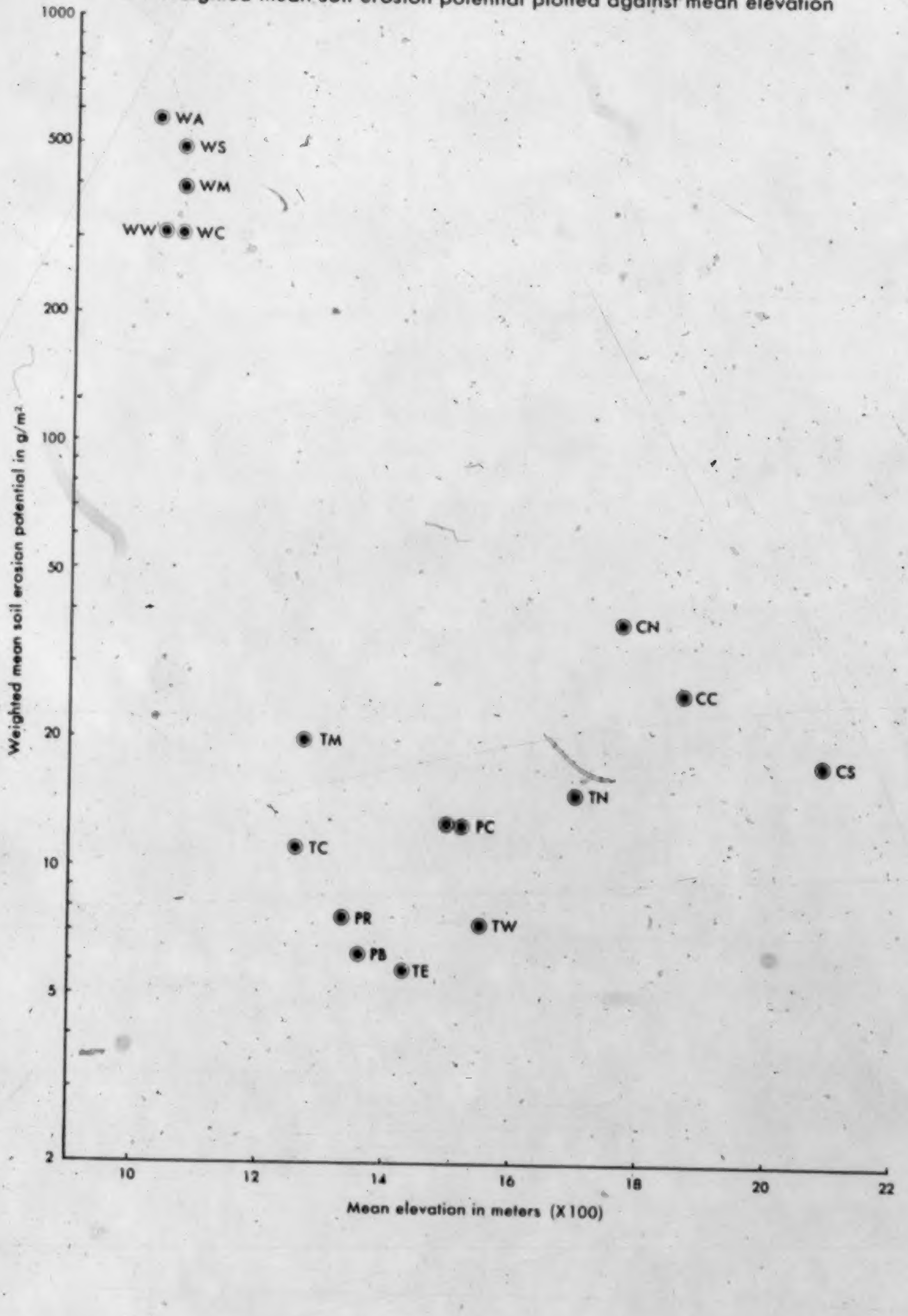


Figure 8-4

Weighted mean soil erodibility plotted against mean elevation

Figure 8-5

Weighted mean soil erosion potential plotted against mean elevation



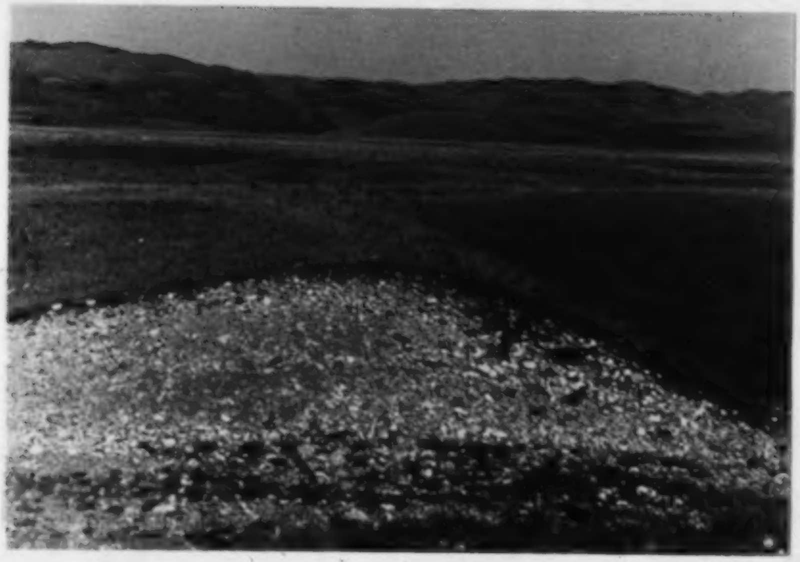


PLATE 3-1 Uppermost terrace level along Pekisko Creek. About 5 km east of Cartwright Section (Sect. 26-16-4-W5). Note the hummocky appearance of the level and calcareous till deposit.

PLATE 3-2 Terrace levels in lower Three Point Creek. Looking east from the uppermost level. Lowest level is beyond the willow grove to the right.

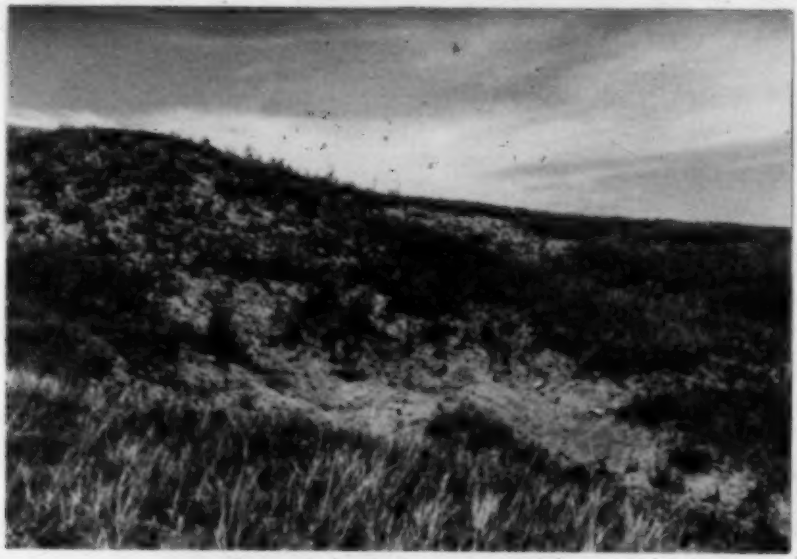


PLATE 3-3 Overly grazed areas in Campbell Section (Sect. 32-19-24-W4), A sizeable area of this coulee in the eastern part of the section has developed into a badland type of topography.

PLATE 3-4 Incipient gullying in Campbell Section (Sect. 32-19-24-W4), West Arrowwood Creek. Located immediately north of plot #W2 (Fig. 3-12).

PLATE 3-5 Eolian deposits in Merkel Section (Sect. 24-19-25-W4), West Arrowwood Creek. Located in northeast corner of section (Fig. 3-13).

PLATE 3-6 Local sedimentation in ditches, Merkel Section (Sect. 24-19-25-W4), West Arrowwood Creek. These are mainly fine wash deposits found in the northwest (Fig. 3-13).

PLATE 3-7 Shallow slumping in Steiner Section (Sect. 31-18-24-W4), West Arrowwood Creek. Cattle trail is found adjacent to slump. Note shallow slumping scars in background. They are the ones found near site #11 (Fig. 3-14).

PLATE 3-8 Cutbanks along coulee, Steiner Section (Section. 31-18-24-W4), West Arrowwood Creek. Looking south from south of site #4 (Fig. 3-14).

PLATE 3-9 Erosion on cultivated land, Weber Section (Sect. 7-20-25-W4), West Arrowwood Creek. Note the slightly steeper slope to the left.

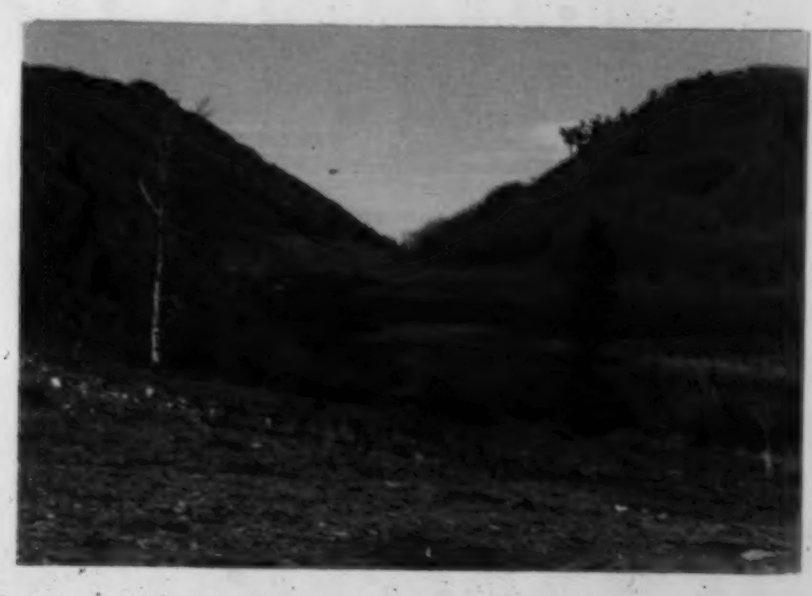


PLATE 3-10 Valley form in upper Stimson Creek, Smith Section (Sect. 23-15-3-W5). Typical V-shaped valley in western part of section (Fig. 3-18) developed on Mesozoic sandstones.

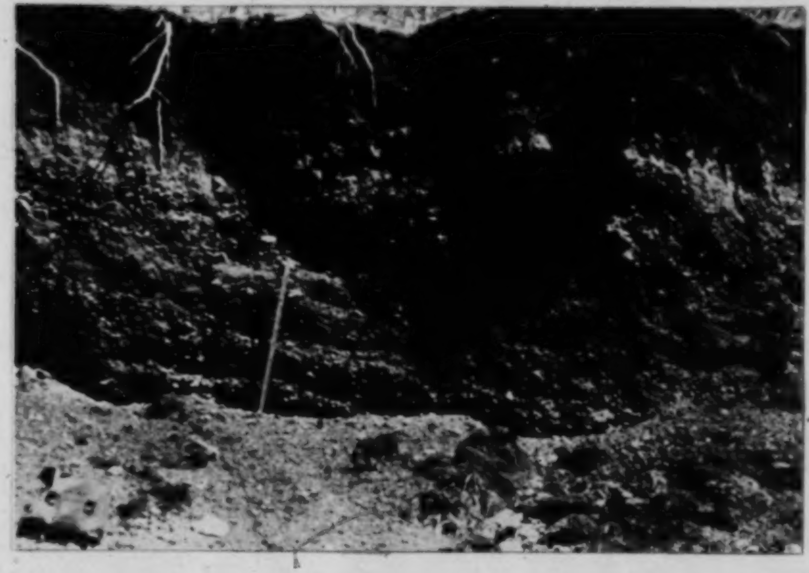


PLATE 3-11 Sand and gravel deposits, Smith Section (Sect. 23-15-3-W5), Stimson Creek. Note deep soil horizons developed. Scale is given by three-foot ruler.

PLATE 3-12 Outwash deposits, upper Three Point Creek. Outwash deposits resting on Belly River Sandstone and Interbedded Shales to the left. Scale is given by three-foot ruler.

PLATE 3-13 High cutbank along central valley, Cataract South Section. Relief is about 15 m. Cutbank developed on Fernie Shales.

PLATE 4-1 Closeup of erosion plot, Plot #C4, Cataract North Section.

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APPENDIX 4-1

Excerpt from Paper by BRYAN, R.B. :

"An improved rainfall simulator for use in erosion research"

Canadian Journal of Earth Sciences, v.7, 1552-1561.

Design of the "Edmonton-pattern" Rainfall Simulator

Although the basic principles of the Sheffield unit were adhered to in the new simulator, it was completely redesigned to incorporate modifications and to take advantage of a larger laboratory. This made it possible to house a unit with an appreciably larger fall-height, allowing a closer approach to terminal velocity for falling drops. The completed unit is 2.77 m high, compared with the 2.16 m of the Sheffield unit; the respective fall-heights are 2.59 m and 1.66 m. The basic framework consists of a 5 x 5 cm welded angle steel sheathed on two sides by perspex, allowing observation of samples during experiments. The floor area of the unit is 1.53 x 0.61 m. A basal tank of sheet aluminum rests in the framework 45.72 cm above the floor. Its basic dimensions are 1.53 x 0.61 x 0.13 m, but the base slopes 2.5° to permit free drainage to a 3.8 cm diameter copper outlet pipe.

One improvement suggested by work with the Sheffield unit was the development of a sample pan which would permit separation of material splashed and washed off the sample. The resulting sample pan, which rests in the center of the basal tank, is of somewhat complex design, but has proven very satisfactory in operation. It consists of an outer splash pan, 50.8 x 50.8 x 10.2 cm, the#base of which slopes 6° to a slot outlet which passes through the basal tank to a movable collection tank beneath the unit. The splash pan is mounted on a pivot at the downslope end which allows the inclination to be altered from 0 to 30° by means of a worm and screw mechanism. Four 91 cm angle aluminum uprights are attached to the splash pan by wing nuts, permitting the attachment of a polyethylene screen to collect material splashed off the sample. This is a considerable improvement on the Sheffield unit the splash screens of which were only 25 cm high, allowing a significant loss of material. Even using a 91 cm screen there is probably a certain amount of loss, as Ellison's (1945) work has shown that splashed material can rise to 1.53 m above the sample, but observation indicates that the fraction lost is insignificant. The actual sample is contained in a 30.5 x 30.5 x 10.2 cm inner pan, which rests on four metal studs in the base of the splash permitting free movement of washed material beneath it. The sample pan clips under the lip of a second slot outlet, the lip being flush with the surface of the sample, so that all the material washed off the sample passes through the basal tank to a second movable collection tank. The outer surface of this outlet is perspex to allow complete cleaning after each experiment. Access to sample and splash pans is through a 91 x(1 cm door, which seals with a rubber flap.

The simulator spray unit is basically similar to that in the Sheffield unit, but there are a number of detailed design changes. In the Sheffield simulator the position of the spray unit was fixed, the spray rotating through an arc of 5°, while the new unit moves to and fro across the top of the sample through a distance of 30.5 cm. The unit consists of two banks of copper pipes mounted in a rigid framework which rests on nylon-bushed bearings in sliding grooves. Each bank has two parallel, connected 9.5 mm diameter pipes, 7.6 cm apart. The two banks are 45.7 cm apart and are inclined towards one another at a set, though freely adjustable angle. Each pipe is drilled and tapped to take four spray nozzles, 7.6 cm apart, the nozzles of adjacent pipes being staggered. Four nozzle diameters, 0.39, 0.79, 1.58, and 3.16 mm, have been tested in the unit, but an infinitely variable range of nozzle diameters is perfectly feasible. Four taps mounted on the unit, in conjunction with main supply taps allow the four spray pipes to be operated separately or in any combination. The nozzles project spray arcs upwards, the apical height varying with the intensity required, and being limited only by available accommodation and water pressure.

Movement of the spray unit is actuated by a Schrader Recip-ro-pac compressed air motor, mounted on a framework at one end of the unit. The original design provided for an electric motor operating through a piston and crank mechanism, but the compressed air unit proved much more flexible allowing a wide variation in adjustment of speed and stroke length. Speed is adjusted by a screw, while the stroke length can be altered by simple adjustment of a movable collar. During all work carried out so far the stroke length has been fixed at 30.5 cm. The compressed air unit is fitted with a lubricator, and for operating comfort, it also proved necessary to fit it with a muffler.

Water supply to the spray unit is from mains via a 9.5 mm diameter copper pipe, which splits to supply each bank of the unit separately. Two simple flow gauges were originally fitted, but proved insufficiently accurate for steady operation at the very low water pressure required (invariably less than 2 p.s.i.). Two Fisher type 922 pressure regulators were subsequently incorporated providing flow control adjustable from 0.5 to 2.5 p.s.i.

APPENDIX B-2
VALUES OF θ_d FOR DETERMINATION OF PARTICLE SIZE FROM OBSERVED HYDROMETER READINGS
(FOR HYDROMETER ASTM 151H)

R_1	θ_d	R_1	θ_d	R_1	θ_d	R_1	θ_d	R_1	θ_d
0.1	49.13	3.1	47.94	6.1	46.68	9.1	45.42	12.1	44.09
0.2	49.09	3.2	47.90	6.2	46.64	9.2	45.38	12.2	44.04
0.3	49.05	3.3	47.86	6.3	46.60	9.3	45.34	12.3	44.00
0.4	49.01	3.4	47.82	6.4	46.56	9.4	45.29	12.4	43.95
0.5	49.97	3.5	47.78	6.5	46.52	9.5	45.25	12.5	43.91
0.6	49.93	3.6	47.74	6.6	46.48	9.6	45.20	12.6	43.87
0.7	48.90	3.7	47.70	6.7	46.44	9.7	45.16	12.7	43.83
0.8	48.86	3.8	47.66	6.8	46.39	9.8	45.11	12.8	43.78
0.9	48.82	3.9	47.62	6.9	46.35	9.9	45.07	12.9	43.74
1.0	48.78	4.0	47.58	7.0	46.31	10.0	45.02	13.0	43.69
1.1	48.74	4.1	47.54	7.1	46.27	10.1	44.97		
1.2	48.70	4.2	47.49	7.2	46.22	10.2	44.92		
1.3	48.66	4.3	47.45	7.3	46.18	10.3	44.88		
1.4	48.62	4.4	47.40	7.4	46.14	10.4	44.83		
1.5	48.58	4.5	47.36	7.5	46.10	10.5	44.79		
1.6	48.54	4.6	47.31	7.6	46.06	10.6	44.75		
1.7	48.51	4.7	47.27	7.7	46.02	10.7	44.71		
1.8	48.47	4.8	47.23	7.8	45.98	10.8	44.67		
1.9	48.43	4.9	47.19	7.9	45.94	10.9	44.63		
2.0	48.39	5.0	47.15	8.0	45.89	11.0	44.58		
2.1	48.35	5.1	47.11	8.1	45.85	11.1	44.54		
2.2	48.31	5.2	47.07	8.2	45.80	11.2	44.49		
2.3	48.27	5.3	47.03	8.3	45.76	11.3	44.45		
2.4	48.22	5.4	46.98	8.4	45.72	11.4	44.40		
2.5	48.18	5.5	46.94	8.5	45.68	11.5	44.35		
2.6	48.14	5.6	46.90	8.6	45.63	11.6	44.30		
2.7	48.10	5.7	46.86	8.7	45.59	11.7	44.26		
2.8	48.06	5.8	46.81	8.8	45.54	11.8	44.21		
2.9	48.02	5.9	46.77	8.9	45.50	11.9	44.17		
3.0	47.98	6.0	46.72	9.0	45.46	12.0	44.13		

R_1 = Hydrometer Scale Reading (g/liter); θ_d = Sedimentation parameter based on a temperature of

30°C and a particle density of 2.650 g/ml for ASTM hydrometer 151H, calculated according to documentation by Day (1955,1956).

APPENDIX 5-1A SOIL LOSS VARIABLES OF TESTED SAMPLES

SITE	DRY	RUN		WET	RUN		TOTAL			WITH COVER SIMULATION*		
	WASH LOSS	SPLASH LOSS	TOTAL LOSS	WASH LOSS	SPLASH LOSS	TOTAL LOSS	WASH LOSS	SPLASH LOSS	TOTAL LOSS	WASH LOSS	SPLASH LOSS	TOTAL LOSS
CC03	10.9	6.5	17.4	9.7	10.2	19.9	17.4	19.9	37.3	9.1	10.6	19.6
CC04	69.6	72.1	141.7	78.3	82.0	160.3	141.7	160.3	302.0	21.1	32.3	53.4
CC06	34.8	58.4	93.2	54.7	52.2	106.9	93.2	106.9	200.1	0.0	0.0	0.0
CC07	13.7	13.7	27.3	10.8	11.8	22.6	27.3	22.6	50.0	0.0	0.0	0.0
CC08	18.6	36.0	54.7	51.0	52.2	103.2	54.7	103.2	157.8	3.7	10.8	14.5
CC09	257.3	135.5	392.8	165.3	128.0	293.3	392.8	293.3	686.1	0.0	0.0	0.0
CC11	226.2	251.1	477.3	340.6	200.1	540.7	477.3	540.7	1017.9	0.0	0.0	0.0
CC12	151.6	164.1	315.7	252.3	200.1	452.4	315.7	452.4	768.1	0.0	0.0	0.0
CC13	428.8	309.5	738.3	402.7	320.7	723.4	738.3	723.4	1461.7	0.0	0.0	0.0
CN01	4.4	55.7	60.1	19.7	103.8	123.5	60.1	123.5	183.6	8.5	18.6	27.1
CN03	111.9	251.1	362.9	310.7	384.1	694.8	362.9	694.8	1057.7	28.6	165.3	193.9
CN05	7.1	8.5	15.5	12.4	6.8	19.3	15.5	19.3	34.8	7.5	6.6	14.0
CN06	77.1	95.7	172.8	118.1	213.8	331.9	172.8	331.9	504.6	0.0	0.0	0.0
CN07	3.9	208.0	211.9	6.3	366.5	372.7	211.9	372.7	584.6	0.0	0.0	0.0
CN09	79.5	210.1	289.6	129.3	221.2	350.5	289.6	350.5	640.1	0.0	0.0	0.0
CS01	1.5	59.3	60.8	1.9	136.9	138.8	60.8	138.8	199.6	0.0	0.0	0.0
CS02	1.6	62.5	64.1	3.6	155.2	158.8	64.1	158.8	222.9	0.0	0.0	0.0
CS04	5.0	67.8	72.8	8.1	129.0	137.1	72.8	137.1	209.9	0.0	0.0	0.0
CS05	6.2	133.3	139.6	17.5	292.9	310.4	139.6	310.4	450.0	0.0	0.0	0.0
CS07	51.0	105.6	156.6	79.5	167.8	247.3	156.6	247.3	403.9	6.8	33.6	40.4
CS08	34.8	83.3	118.1	63.4	150.4	213.8	118.1	213.8	331.9	0.0	0.0	0.0
PB01	53.4	116.8	170.3	73.3	174.0	247.3	170.3	247.3	417.6	29.8	78.3	108.1
PB02	44.7	109.4	154.1	67.1	196.4	263.5	154.1	263.5	417.6	39.8	101.9	141.7
PB03	0.4	8.7	9.2	1.1	16.4	17.5	9.2	17.5	26.7	0.2	2.7	3.0
PB59	0.3	33.4	33.7	0.3	38.8	39.1	33.7	39.1	72.9	0.2	10.8	11.0
PB60	4.4	85.3	89.6	2.5	88.5	91.0	89.6	91.0	180.7	2.7	7.7	10.4
PB61	4.4	92.9	97.3	7.7	188.0	195.6	97.3	195.6	292.9	2.2	45.9	48.1
PB62	1.0	48.5	49.5	4.0	109.9	113.9	49.5	113.9	163.4	0.5	16.2	16.7
PB64	2.0	41.5	43.5	4.9	83.1	88.0	43.5	88.0	131.5	2.4	10.9	13.3
PB65	2.7	26,2	29.0	2.5	42.6	45.1	29.0	45.1	74.1	1.1	4.4	5.5
PB66	48.5	165.3	213.8	59.7	252.3	312.0	213.8	312.0	525.8	6.8	39.8	46.6
PB67	3.3	78.7	82.0	10.9	137.7	148.6	82.0	148.6	230.6	0.0	0.0	0.0
PB68	38.5	77.1	115.6	52.2	114.3	166.5	115.6	166.5	282.1	1.9	8.7	10.6
PB69	6.2	184.7	190.9	14.2	274.3	288.5	190.9	288.5	479.5	4.9	23.0	27.9
PB70	27.3	90.7	118.1	51.0	186.4	237.4	118.1	237.4	355.5	3.4	13.7	17.0
PB71	1.6	33.9	35.5	5.0	74.3	79.3	35.5	79.3	114.9	0.5	8.7	9.3
PB73	8.0	206.6	214.6	17.5	354.1	371.6	214.6	371.6	586.2	10.4	48.1	58.5
PC13	2.6	60.4	62.9	4.4	131.5	135.9	62.9	135.9	198.9	4.4	11.9	16.3
PC14	98.2	128.0	226.2	152.9	155.4	308.2	226.2	308.2	534.5	10.8	32.3	43.1
PC15	1.5	36.6	38.2	1.9	70.1	72.0	38.2	72.0	110.2	0.0	0.0	0.0
PC16	49.7	109.4	159.1	58.4	150.4	208.8	159.1	208.8	367.9	9.6	31.1	40.6
PC17	68.4	139.2	207.6	87.0	232.4	319.4	207.6	319.4	527.0	11.6	41.0	52.6
PC18	4.0	159.6	163.6	7.4	303.8	311.3	163.6	311.3	474.9	4.2	55.7	59.9
PC20	14.9	14.9	29.8	26.1	32.3	58.4	29.8	58.4	88.2	5.6	13.7	19.3
PC21	33.6	63.4	96.9	74.6	155.4	229.9	96.9	229.9	326.9	32.3	72.1	104.4
PC22	38.5	100.7	139.2	78.3	213.8	292.1	139.2	292.1	431.3	0.0	0.0	0.0
PC23	27.3	79.5	106.9	57.2	264.7	321.9	106.9	321.9	428.8	13.7	37.3	51.0
PC24	3.3	80.9	84.2	4.6	125.7	130.3	84.2	130.3	214.4	1.9	8.3	10.2
PC25	26.1	49.7	75.8	44.7	90.7	135.5	75.8	135.5	211.3	7.5	13.7	21.1
PC26	22.4	53.4	75.8	42.3	99.4	141.7	75.8	141.7	217.5	13.7	51.0	64.6
PC27	3.6	41.5	45.1	5.2	119.1	124.4	45.1	124.4	169.5	2.1	14.2	16.3
PC29	55.9	120.6	176.5	90.7	175.3	266.0	176.5	266.0	442.5	7.6	38.5	46.1

PC31	2.9	93.8	96.7	12.9	174.6	187.5	96.7	187.5	284.2	11.0	39.9	50.9
PC32	1.4	41.5	43.0	3.8	102.7	106.6	43.0	106.6	149.5	0.5	15.3	15.8
PC33	2.4	24.0	26.4	5.5	45.9	51.4	26.4	51.4	77.8	0.0	0.0	0.0
PC38	139.2	184.0	323.2	268.5	237.4	505.9	323.2	505.9	829.0	92.0	135.5	227.5
PC39	49.7	88.2	138.0	77.1	191.4	268.5	138.0	268.5	406.4	11.2	14.9	26.1
PC40	22.4	49.7	72.1	38.5	108.1	146.7	72.1	146.7	218.8	4.1	22.4	26.5
PC42	5.8	80.9	86.7	14.2	180.3	194.5	86.7	194.5	281.2	3.8	23.0	26.8
PR01	1.6	9.8	11.5	0.9	19.7	20.5	11.5	20.5	32.0	1.9	6.2	8.1
PR02	7.7	112.6	120.2	14.2	210.9	225.2	120.2	225.2	345.4	10.9	19.7	30.6
PR04	10.3	41.0	51.3	34.8	108.1	142.9	51.3	142.9	194.3	5.0	17.4	22.4
PR07	6.0	9.7	15.7	14.9	17.4	32.3	15.7	32.3	48.0	0.9	6.2	7.1
PR08	0.2	7.5	7.8	0.5	14.0	14.6	7.8	14.6	22.3	0.1	7.0	7.1
PR09	111.5	294.0	405.5	298.4	501.7	800.1	405.5	800.1	1205.5	6.6	72.1	78.7
PR12	28.6	67.1	95.7	52.2	147.9	200.1	95.7	200.1	295.8	2.7	13.7	16.4
PR13	0.9	15.3	16.2	4.2	30.6	34.8	16.2	34.8	50.9	1.1	4.4	5.5
PS01	1.1	93.8	94.9	1.8	172.5	174.3	94.9	174.3	269.1	1.1	20.5	21.6
PS02	49.7	105.6	155.4	78.3	181.5	259.8	155.4	259.8	415.1	6.2	12.4	18.6
PS04	0.3	7.7	8.0	0.3	16.4	16.7	8.0	16.7	24.7	0.3	7.3	7.7
PS05	1.1	19.7	20.8	2.2	30.6	32.8	20.8	32.8	53.6	0.8	3.3	4.0
PS09	5.6	12.4	18.0	9.9	11.8	21.8	18.0	21.8	39.8	2.0	6.8	8.8
PS10	41.0	131.7	172.8	44.7	134.2	179.0	172.8	179.0	351.7	1.9	8.9	10.8
PS15	26.1	65.9	92.0	58.4	124.3	182.7	92.0	182.7	274.7	10.3	29.8	40.1
TC18	55.9	150.4	206.3	70.8	188.9	259.8	206.3	259.8	466.1	19.9	32.3	52.2
TC19	16.2	42.3	58.4	28.6	63.4	92.0	58.4	92.0	150.4	1.4	6.6	8.0
TC24	0.9	23.0	23.8	3.4	54.6	58.0	23.8	58.0	81.9	0.2	10.9	11.1
TC28	0.5	33.9	34.4	5.1	110.4	115.5	34.4	115.5	150.0	2.0	32.8	34.8
TC32	0.5	24.0	24.6	2.7	54.6	57.4	24.6	57.4	82.0	0.2	10.9	11.1
TC33	0.1	16.2	16.3	0.9	42.0	42.9	16.3	42.9	59.2	0.0	0.0	0.0
TC34	13.7	31.1	44.7	24.9	48.5	73.3	44.7	73.3	118.1	0.0	0.0	0.0
TC36	16.2	53.4	69.6	33.6	106.9	140.4	69.6	140.4	210.1	1.9	21.1	23.0
TC37	1.0	38.8	39.8	3.8	64.7	68.4	39.8	68.4	108.2	0.0	0.0	0.0
TC38	0.1	7.0	7.1	0.1	11.9	12.0	7.1	12.0	19.1	0.0	0.0	0.0
TE01	33.6	108.1	141.7	54.7	177.7	232.4	141.7	232.4	374.1	3.6	52.2	55.8
TE02	29.8	82.0	111.9	43.5	118.1	161.6	111.9	161.6	273.4	0.0	0.0	0.0
TE03	70.8	187.7	258.5	84.5	215.0	299.5	258.5	299.5	558.1	12.3	99.4	111.7
TE05	12.0	108.2	120.2	13.1	168.3	181.4	120.2	181.4	301.7	0.0	0.0	0.0
TE09	2.2	45.3	47.4	2.8	90.5	93.3	47.4	93.3	140.8	0.0	0.0	0.0
TE13	2.7	66.7	69.4	4.5	204.4	208.9	69.4	208.9	278.3	0.0	0.0	0.0
TE14	12.0	256.8	268.9	80.9	312.6	393.5	268.9	393.5	662.3	0.0	0.0	0.0
TE16	94.5	293.3	387.8	287.1	297.1	584.2	387.8	584.2	972.0	0.0	0.0	0.0
TH02	0.3	6.2	6.6	0.3	5.7	6.0	6.6	6.0	12.6	0.0	0.0	0.0
TH04	3.1	55.7	58.8	6.0	104.9	110.9	58.8	110.9	169.7	1.9	17.5	19.3
TH06	0.8	17.2	18.0	1.4	63.6	65.0	18.0	65.0	83.0	0.1	7.2	7.3
TH09	0.5	51.4	51.9	9.6	138.8	148.4	51.9	148.4	200.3	3.0	15.3	18.3
TH10	18.6	29.8	48.5	34.8	74.6	109.4	48.5	109.4	157.8	3.1	14.9	18.0
TH12	3.3	18.6	21.9	6.6	50.3	56.8	21.9	56.8	78.7	3.1	14.2	17.3
TM06	128.0	233.7	361.7	298.3	264.7	563.0	361.7	563.0	924.7	3.1	17.4	20.5
TM07	3.6	38.3	41.9	6.6	55.7	62.3	41.9	62.3	104.2	0.0	0.0	0.0
TM10	2.0	10.9	12.9	4.6	25.1	29.7	12.9	29.7	42.6	0.0	0.0	0.0
TM13	32.3	34.8	67.1	33.6	39.8	73.3	67.1	73.3	140.4	6.8	11.2	18.0
TW01	1.1	23.0	24.0	2.0	37.2	39.1	24.0	39.1	63.2	1.4	12.0	13.4
TW03	7.0	120.2	127.2	21.9	196.7	218.6	127.2	218.6	345.8	0.0	0.0	0.0
TW05	29.8	55.9	85.8	58.4	98.2	156.6	85.8	156.6	242.4	9.9	23.6	33.6
TW08	2.0	40.4	42.4	5.7	114.8	120.4	42.4	120.4	162.9	1.6	27.3	29.0
TW11	878.7	415.[illegible]	1293.9	814.1	390.3	1204.4	1293.9	1204.4	2498.2	0.0	0.0	0.0
TW12	1.2	7.5	8.7	1.2	9.8	11.0	8.7	11.0	19.8	0.0	0.0	0.0
TW13	34.8	55.9	90.7	36.0	60.9	96.9	90.7	96.9	187.7	0.0	0.0	0.0
TW16	136.7	229.9	366.7	200.1	169.0	369.1	366.7	369.1	735.8	0.0	0.0	0.0
TW18	2.5	90.5	93.0	4.5	186.5	191.0	93.0	191.0	284.0	0.0	0.0	0.0
TW20	0.5	64.7	65.2	3.2	85.2	88.4	65.2	88.4	153.6	0.1	8.1	8.2

WA01	63.4	213.8	277.2	333.1	360.4	693.5	277.2	693.5	970.7	0.0	0.0	0.0
WA02	22.6	460.3	482.9	98.1	350.3	448.4	482.9	448.4	931.3	67.9	185.4	253.3
WA03	25.9	789.0	814.9	42.0	662.9	704.9	814.9	704.9	1519.8	0.0	0.0	0.0
WA04	32.3	495.8	528.2	184.3	447.3	631.6	528.2	631.6	1159.8	49.6	270.5	320.1
WC01	98.1	451.6	549.7	315.8	612.2	928.0	549.7	928.0	1477.8	107.8	250.1	357.9
WC02	3.5	[illegible]	124.2	21.9	273.2	295.1	124.2	295.1	419.3	32.8	201.1	233.9
WC03	2.2	61.2	63.4	2.7	171.6	174.3	63.4	174.3	237.7	3.8	111.5	115.3
WC04	85.3	559.6	644.9	299.5	665.6	965.1	644.9	965.1	1609.9	0.0	0.0	0.0
WC05	51.0	167.8	218.8	90.7	293.3	384.1	218.8	384.1	602.8	7.2	18.6	25.9
WC06	196.4	345.5	541.9	454.9	339.3	794.2	541.9	794.2	1336.1	0.0	0.0	0.0
WC07	9.3	706.0	715.3	26.9	506.6	533.5	715.3	533.5	1248.8	18.3	292.1	310.4
WC08	114.3	353.0	467.3	341.8	379.1	720.9	467.3	720.9	1188.2	0.0	0.0	0.0
WC09	23.7	761.0	784.7	92.7	664.0	756.7	784.7	756.7	1541.4	0.0	0.0	0.0
WM01	22.6	790.1	812.7	62.5	632.7	695.2	812.7	695.2	1507.9	0.0	0.0	0.0
WM02	12.9	725.4	738.3	38.8	570.2	609.0	738.3	609.0	1347.3	28.0	323.4	351.4
WM03	12.0	325.7	337.7	103.8	443.7	547.6	337.7	547.6	885.3	41.5	277.6	319.1
WM04	10.6	809.5	820.0	21.6	601.5	623.0	820.0	623.0	1443.1	9.9	335.2	345.1
WM05	8.0	587.4	595.4	18.3	533.5	551.9	595.4	551.9	1147.3	1.1	23.7	24.8
WM06	523.3	305.8	829.0	698.5	336.8	1035.3	829.0	1035.3	1864.4	0.0	0.0	0.0
WM07	44.2	534.6	578.8	88.4	526.0	614.4	578.8	614.4	1193.2	35.6	199.4	235.0
WM89	92.0	326.9	418.9	364.2	350.5	714.7	418.9	714.7	1133.5	0.0	0.0	0.0
WM99	94.5	264.7	359.2	185.2	372.9	558.1	359.2	558.1	917.3	0.0	0.0	0.0
WM09	4.4	102.7	107.1	26.2	262.3	288.5	107.1	288.5	395.7	1.6	20.8	22.4
WM10	5.5	394.5	400.0	14.0	587.4	601.5	400.0	601.5	1001.4	3.0	142.3	145.3
WM11	70.8	264.7	335.6	130.5	359.2	489.7	335.6	489.7	825.3	0.0	0.0	0.0
WS01	60.9	180.2	241.1	93.2	264.7	358.0	241.1	358.0	599.1	12.4	19.9	32.3
WM03	60.9	207.6	268.5	179.0	312.0	490.9	268.5	490.9	759.4	12.4	43.5	55.9
WS04	2.2	130.4	132.6	5.7	309.3	315.1	132.6	315.1	447.6	1.7	32.3	34.1
WS06	23.7	860.1	683.9	90.5	694.1	784.7	883.9	784.7	1668.5	0.0	0.0	0.0
WS07	62.5	697.4	759.9	162.8	860.1	1022.9	759.9	1022.9	1782.8	0.0	0.0	0.0
WS08	19.4	316.9	336.3	142.3	362.2	504.4	336.3	504.4	840.7	88.4	217.7	306.1
WS09	148.7	445.2	593.9	365.4	342.8	708.2	593.9	708.2	1302.1	103.5	215.6	319.0
WS10	186.4	285.9	472.3	433.8	269.7	703.5	472.3	703.5	1175.8	0.0	0.0	0.0
WS11	195.1	328.1	523.3	449.9	298.3	748.2	523.3	748.2	1271.5	60.9	218.8	279.7
WW01	102.4	372.9	475.3	178.9	295.3	474.3	475.3	474.3	949.6	29.1	178.9	208.0
WW02	11.9	241.4	253.3	19.4	292.1	311.5	253.3	311.5	564.8	0.0	0.0	0.0
WW03	12.9	681.2	694.1	22.6	526.0	548.6	694.1	548.6	1242.8	7.4	339.5	347.0
WW04	47.2	144.2	191.4	80.8	225.0	305.8	191.4	305.8	497.2	9.6	21.1	30.7
WW05	81.9	353.5	435.5	172.5	401.0	573.4	435.5	573.4	1008.9	6.1	23.7	29.9

*FOR RUN WITH COVER SIMULATION, 0.0 INDICATES NO DATA AVAILABLE; SOIL LOSS IN G/SQ M

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APPENDIX 5-1B SOIL PROPERTIES VARIABLES

SITE	WSA >3.0MM (%)	WSA >2.0MM (%)	WSA >1.0MM (%)	WSA >0.5MM (%)	MWD (MM)	GMD (MM)	MOIST URE (%)	SAND (%)	SILT (%)	CLAY (%)	CRSD 0.5-4.0 MM (%)	ORG CARBON (%)	BULK DENSITY (G/CC)
CC03	3.1	28.5	37.3	46.6	1.06	0.64	2.1	92	6	2	75.6	0.72	1.38
CC04	1.1	9.4	12.8	21.6	0.55	0.36	2.1	77	17	6	54.2	0.94	1.39
CC06	4.7	15.9	16.1	21.4	0.67	0.39	2.1	74	18	8	60.5	1.05	1.29
CC07	1.5	7.4	19.1	29.2	0.62	0.41	2.3	78	14	8	62.6	0.51	1.44
CC08	25.6	44.1	63.7	73.2	1.75	1.17	3.1	30	44	26	9.4	3.38	0.60
CC09	15.5	24.8	27.9	41.5	0.58	0.57	2.1	51	33	16	49.7	1.25	1.19
CC11	8.1	11.5	16.9	25.4	0.69	0.40	2.5	63	22	15	31.4	1.19	1.20
CC12	14.4	21.2	26.6	35.6	0.96	0.52	2.1	60	25	15	27.0	0.96	1.27
CC13	3.7	8.4	10.5	13.6	0.51	0.33	2.2	45	32	23	4.6	2.73	1.35
CN01	8.6	19.1	38.8	51.8	1.06	0.65	2.2	47	33	20	24.2	2.52	0.88
CN03	2.6	4.6	6.9	14.0	0.44	0.32	1.5	63	28	9	31.1	2.20	1.15
CN05	0.0	18.2	29.9	31.3	0.80	0.47	1.8	86	8	6	83.7	0.90	1.43
CN06	10.6	21.8	38.4	45.7	1.07	0.62	2.2	74	15	11	52.5	1.03	1.02
CN07	3.9	8.1	15.9	26.0	0.61	0.39	1.9	64	24	12	14.3	2.32	0.97
CN09	3.7	10.3	22.2	36.6	0.73	0.46	2.3	40	40	20	24.6	1.55	0.91
CS01	3.3	8.3	20.7	37.2	0.70	0.46	6.5	36	56	8	6.2	12.32	0.56
CS02	12.6	22.2	42.9	60.5	1.20	0.76	3.7	30	49	21	8.7	4.68	0.63
CS04	12.5	20.8	40.6	57.1	1.16	0.72	2.9	50	28	22	26.2	2.89	1.82
CS05	5.9	8.9	20.2	34.3	0.71	0.45	2.7	53	32	15	23.8	1.96	0.92
CS07	11.5	19.0	34.8	49.3	1.05	0.62	1.8	56	28	16	19.4	2.84	0.90
CS08	4.4	15.5	23.9	30.5	0.77	0.45	1.8	76	16	8	39.8	0.82	1.07
PB01	2.4	6.2	12.1	19.9	0.52	0.35	3.1	53	33	14	24.0	5.18	0.88
PB02	5.1	16.1	29.9	41.0	0.88	0.53	3.2	52	30	18	37.2	6.91	0.80
PB03	7.1	15.6	30.2	44.5	0.91	0.55	4.1	37	32	31	6.3	11.91	0.52
PB59	1.8	6.3	13.5	22.1	0.54	0.36	4.4	37	36	27	7.2	14.07	0.63
PB60	1.3	4.4	9.9	17.4	0.46	0.33	5.5	36	37	27	2.9	14.40	0.53
PB61	3.8	8.1	18.0	31.8	0.66	0.42	4.5	33	42	25	3.2	8.11	0.75
PB62	1.3	2.8	6.8	13.8	0.41	0.31	5.9	36	37	27	6.2	14.13	0.61
PB64	8.5	18.3	33.9	53.4	1.02	0.64	5.5	33	48	19	2.7	13.86	0.56
PB65	6.1	14.4	27.1	39.7	0.84	0.51	5.3	33	30	37	7.2	13.33	0.54
PB66	10.0	20.0	32.9	43.3	1.00	0.58	2.7	52	34	14	5.4	5.74	0.74
PB67	6.5	14.9	31.8	44.6	0.91	0.56	2.8	31	37	32	14.6	3.65	0.77
PB68	1.8	4.9	11.0	20.8	0.50	0.35	3.9	39	32	29	8.2	7.32	0.67
PB69	2.3	5.8	12.2	21.9	0.53	0.36	4.7	39	42	19	2.3	10.93	0.59
PB70	3.3	6.3	15.1	31.3	0.61	0.41	4.0	36	38	26	7.9	5.58	0.78
PB71	6.4	12.4	25.6	40.3	0.82	0.50	4.4	28	45	27	2.0	11.05	0.71
PB73	2.3	5.3	10.9	18.9	0.50	0.34	4.3	31	36	33	5.8	7.93	0.77
PC13	3.4	7.2	14.5	25.0	0.58	0.38	4.5	35	37	28	11.3	10.80	0.66
PC14	8.4	16.9	32.8	49.4	0.98	0.60	2.1	39	38	23	21.7	3.63	1.04
PC15	5.8	11.8	26.1	42.4	0.82	0.51	4.0	33	44	23	5.2	7.55	0.72
PC16	4.9	8.4	13.6	21.2	0.58	0.37	3.3	42	29	29	21.6	9.09	0.83
PC17	6.5	9.8	17.7	29.2	0.68	0.42	4.3	37	45	18	16.4	10.10	0.77
PC18	4.3	8.3	15.8	24.8	0.61	0.39	5.6	36	39	25	10.8	13.45	0.62
PC20	9.5	19.3	39.9	58.4	1.11	0.71	3.3	32	37	31	17.1	7.77	0.71
PC21	2.4	8.8	17.7	40.1	0.69	0.46	2.6	37	37	26	31.5	3.46	0.97
PC22	6.5	12.3	22.9	35.8	0.78	0.47	4.1	35	45	20	13.6	10.63	0.74
PC23	5.4	9.3	17.1	27.1	0.65	0.40	3.1	46	26	28	24.3	9.23	0.86
PC24	3.5	8.9	17.2	25.9	0.63	0.40	3.7	39	35	26	14.8	10.38	0.80
PC25	3.4	8.4	16.9	27.7	0.63	0.40	3.2	41	44	15	12.4	8.10	0.76
PC26	11.4	22.6	40.7	57.4	1.16	0.72	1.7	19	46	35	29.8	1.51	1.09
PC27	7.5	14.5	25.3	35.9	0.83	0.49	2.5	47	34	19	31.5	4.57	0.99
PC29	0.4	1.6	3.1	7.2	0.33	0.28	1.9	76	16	8	13.4	3.90	1.08

PC31	1.8	4.7	7.6	13.8	0.44	0.32	4.3	41	33	26	19.5	12.38	0.78
PC32	5.6	10.0	22.4	40.3	0.77	0.49	2.1	37	38	25	7.5	4.85	0.88
PC33	6.9	15.8	39.6	61.5	1.07	0.71	2.8	31	42	27	14.4	5.09	0.84
PC38	7.7	14.5	31.7	51.1	0.95	0.60	1.9	37	37	26	28.9	2.57	1.13
PC39	0.3	4.6	9.2	17.0	0.45	0.33	3.9	45	34	21	20.8	9.84	0.72
PC40	1.6	5.4	12.4	22.6	0.52	0.36	3.7	38	37	25	16.0	10.86	0.70
PC42	1.6	6.6	15.7	25.5	0.57	0.38	4.1	38	37	25	14.0	10.71	0.75
PR01	13.5	22.3	36.6	51.8	1.12	0.66	5.2	33	31	36	0.9	11.33	0.61
PR02	5.2	12.2	23.9	36.7	0.78	0.48	3.9	30	31	39	6.5	7.37	0.73
PR04	5.9	13.3	31.0	48.5	0.75	0.55	2.8	22	40	38	6.7	3.58	0.86
PR07	6.3	14.3	37.4	59.9	1.02	0.68	3.2	27	41	32	6.7	3.24	0.87
PR08	5.2	11.3	27.0	47.8	0.85	0.55	6.4	34	40	26	0.8	15.50	0.54
PR09	0.8	4.8	14.0	28.8	0.55	0.39	2.9	22	43	35	5.2	1.52	1.12
PR12	3.6	9.9	25.0	43.2	0.78	0.51	3.1	46	26	28	5.7	6.38	0.71
PR13	8.2	19.7	47.0	71.5	1.22	0.86	4.9	18	30	52	0.9	5.62	0.78
PS01	2.3	5.8	16.5	32.8	0.61	0.42	3.5	51	27	22	11.7	6.55	0.76
PS02	0.1	4.1	8.1	17.0	0.44	0.33	2.8	54	28	18	27.6	6.59	0.85
PS04	11.0	24.4	50.8	68.8	1.31	0.88	4.6	36	39	25	5.3	10.51	0.63
PS05	9.4	21.2	42.6	60.8	1.16	0.75	2.9	34	25	41	6.0	7.05	0.68
PS09	7.7	14.1	33.2	57.4	0.99	0.65	3.2	36	33	31	6.9	5.37	0.84
PS10	1.6	5.4	11.9	19.0	0.50	0.35	4.6	49	33	18	14.1	10.99	0.59
PS15	4.4	8.2	22.2	45.6	0.76	0.51	3.5	37	37	26	12.1	4.04	0.91
TC18	6.1	16.5	26.5	38.7	0.85	0.51	2.7	62	25	13	19.5	5.13	0.77
TC19	5.7	12.6	22.6	31.7	0.75	0.45	3.2	56	21	23	8.2	6.57	0.72
TC24	3.7	7.5	20.1	38.8	0.70	0.46	4.1	28	45	27	5.4	6.60	0.73
TC28	4.5	14.3	33.4	52.6	0.94	0.61	4.6	28	39	33	3.0	7.87	0.91
TC32	9.7	22.8	44.4	63.2	1.20	0.78	3.8	34	40	26	7.9	7.64	0.72
TC33	4.4	10.8	26.7	45.7	0.82	0.53	4.3	34	34	32	5.8	7.35	0.67
TC34	8.6	14.2	34.9	57.6	1.02	0.66	4.2	37	38	25	3.3	5.33	0.82
TC36	3.9	15.5	20.6	27.0	0.72	0.42	3.5	30	30	40	2.3	8.77	0.72
TC37	6.7	13.7	18.4	27.2	0.72	0.42	1.4	27	62	11	48.1	1.66	1.19
TC38	28.7	46.9	70.4	82.2	1.91	1.39	2.7	31	46	23	1.8	5.49	0.74
TE01	5.2	11.0	23.1	42.7	0.79	0.50	2.1	36	34	30	20.7	3.29	1.04
TE02	4.8	9.8	19.6	31.4	0.69	0.43	3.7	39	47	14	9.2	9.62	0.74
TE03	3.1	8.2	16.6	29.8	0.63	0.41	2.4	38	36	26	21.6	4.83	0.92
TE05	4.4	10.6	27.5	39.9	0.80	0.50	4.3	35	35	30	7.6	10.36	0.70
TE09	5.3	12.6	33.8	53.0	0.94	0.61	3.0	38	45	17	7.7	6.45	0.73
TE13	6.2	12.4	29.6	49.9	0.90	0.58	4.9	31	50	19	7.0	7.33	0.63
TE14	3.3	9.3	28.9	48.4	0.83	0.55	1.9	31	49	20	10.3	1.87	0.85
TE16	3.6	6.1	8.5	12.8	0.47	0.32	2.0	70	18	12	8.9	0.77	1.08
TM02	11.9	23.4	52.2	72.2	1.34	0.92	3.6	27	52	21	2.9	9.47	0.62
TM04	1.4	3.7	7.0	11.6	0.41	0.30	3.3	58	31	11	12.8	6.07	0.83
TM06	6.0	11.5	31.5	55.1	0.93	0.61	6.2	29	45	26	0.4	8.08	0.85
TM09	3.4	7.5	16.5	30.3	0.63	0.41	4.3	39	35	26	3.3	6.85	0.78
TM10	8.2	15.7	31.2	48.8	0.95	0.59	3.7	34	25	41	9.1	3.35	0.92
TM12	12.9	21.6	37.9	52.9	1.13	0.67	5.4	22	33	45	1.5	8.34	0.76
TN06	15.4	25.0	33.8	43.7	1.10	0.61	1.1	49	39	12	38.0	1.11	1.18
TN07	3.6	9.4	26.0	57.0	0.85	0.59	4.0	41	31	28	15.4	6.85	0.73
TN10	20.9	36.4	62.6	76.9	1.65	1.15	3.2	36	31	33	24.7	4.81	0.79
TN13	12.5	25.1	52.7	71.3	1.36	0.93	3.8	37	22	41	23.5	5.20	0.93
TW01	2.1	7.9	25.0	49.0	0.78	0.53	3.6	43	32	25	24.3	6.50	0.78
TW03	2.7	15.6	27.9	39.2	0.82	0.51	1.9	54	29	17	37.1	0.86	1.10
TW05	2.5	9.4	21.2	36.4	0.70	0.46	2.5	55	27	18	19.5	5.12	0.81
TW08	3.5	7.5	23.7	47.9	0.77	0.52	3.8	30	42	28	9.1	5.73	0.77
TW11	0.0	0.3	0.9	4.0	0.28	0.26	2.8	27	34	39	3.2	1.04	1.07
TW12	23.9	46.2	77.9	88.2	1.94	1.53	3.6	28	45	27	7.3	3.72	0.77
TW13	29.4	46.7	67.4	75.5	1.85	1.27	2.1	24	48	28	22.1	1.71	0.81
TW16	16.0	24.4	34.0	45.2	1.11	0.62	1.6	47	36	17	42.9	1.38	1.00
TW18	16.2	29.9	53.5	74.4	1.46	1.00	4.8	17	44	39	0.9	5.22	0.87
TW20	12.8	25.7	37.1	45.9	1.12	0.63	4.1	32	50	18	9.5	7.73	0.72

WA01	2.1	3.5	7.3	14.4	0.43	0.32	3.1	35	49	16	2.4	4.49	0.74
WA02	0.5	2.8	8.0	15.9	0.42	0.32	2.1	35	38	27	1.4	3.04	0.87
WA03	0.3	0.5	1.1	3.9	0.29	0.26	2.3	45	30	25	3.4	2.60	0.98
WA04	2.1	4.0	8.8	17.6	0.46	0.33	2.3	41	36	23	1.6	3.84	0.90
WC01	0.4	1.0	3.1	9.6	0.63	0.29	3.0	31	44	25	1.3	4.16	0.91
WC02	9.5	15.3	29.7	46.7	0.94	0.57	4.1	29	45	26	1.2	4.90	0.84
WC03	6.3	13.0	25.8	42.1	0.84	0.52	4.9	27	54	19	1.8	10.86	0.66
WC04	0.9	1.6	4.4	11.4	0.36	0.30	3.3	37	39	24	3.2	2.22	1.10
WC05	4.5	8.2	17.6	31.3	0.66	0.42	2.9	41	33	26	4.3	3.75	0.92
WC06	2.4	6.3	12.6	21.4	0.53	0.36	5.6	32	41	27	1.6	0.98	1.06
WC07	0.1	1.0	3.2	9.0	0.33	0.28	2.8	41	37	22	2.3	4.23	0.88
WC08	1.6	3.1	7.7	18.5	0.44	0.33	2.8	67	21	12	8.3	1.17	1.10
WC09	0.5	1.7	5.4	12.1	0.37	0.30	2.7	39	34	27	0.4	4.45	0.83
WM01	0.9	1.6	3.8	8.6	0.35	0.29	2.4	44	34	22	5.5	2.43	1.11
WM02	1.3	2.3	4.6	10.6	0.37	0.28	2.9	40	38	22	0.9	4.29	0.89
WM03	0.2	1.4	3.1	7.6	0.33	0.28	2.5	59	27	14	0.7	2.02	0.89
WM04	0.4	1.1	3.3	9.7	0.34	0.29	2.9	45	31	24	2.1	2.56	0.97
WM05	3.6	6.7	13.4	21.4	0.56	0.36	3.4	39	48	13	4.8	3.71	0.81
WM06	0.1	0.5	6.9	29.0	0.45	0.36	4.6	22	58	20	1.6	0.59	1.07
WM07	0.0	0.7	1.9	6.0	0.30	0.27	2.7	42	33	25	4.2	3.18	0.97
WM89	3.8	7.5	13.5	22.4	0.57	0.37	3.1	37	38	25	0.4	4.27	0.84
WM99	1.2	3.4	11.9	24.1	0.50	0.36	2.2	63	23	14	1.2	1.55	1.02
WM09	8.7	14.3	27.2	42.9	0.89	0.53	2.7	40	37	23	3.7	4.10	0.80
WM10	11.8	18.5	30.6	42.4	0.98	0.56	3.3	42	33	23	0.9	3.41	0.87
WM11	3.4	6.7	20.3	34.6	0.67	0.44	3.1	57	24	19	2.1	1.28	1.06
WS01	1.7	5.6	13.2	23.3	0.53	0.37	3.3	36	44	20	2.0	6.18	0.78
WM03	4.7	9.4	17.1	28.6	0.65	0.41	3.3	47	33	20	0.5	4.51	0.85
WS04	4.8	10.3	23.3	42.1	0.78	0.50	3.3	34	46	20	1.1	5.91	0.80
WS06	2.6	6.4	15.6	26.7	0.58	0.39	2.4	46	37	17	3.1	4.41	0.90
WS07	1.1	2.2	6.1	14.6	0.40	0.31	3.3	24	48	28	0.3	5.45	0.81
WS08	1.0	2.7	9.1	20.8	0.46	0.34	2.8	38	43	19	1.2	4.46	0.80
WS09	0.9	2.0	4.6	9.6	0.36	0.29	2.6	37	43	20	2.0	4.18	0.97
WS10	2.1	4.1	9.4	24.9	0.50	0.36	4.5	55	34	11	18.8	0.39	1.13
WS11	1.0	3.2	10.7	21.9	0.48	0.35	3.7	37	43	20	3.8	1.48	1.07
WW01	0.5	1.0	2.7	7.8	0.32	0.28	2.2	37	31	32	5.7	3.01	0.98
WW02	2.5	4.9	10.4	19.6	0.46	0.34	2.7	45	37	18	4.0	6.52	0.57
WW03	0.7	1.3	2.8	8.1	0.33	0.28	2.3	40	42	18	3.3	4.59	0.92
WW04	7.7	13.5	23.9	36.3	0.81	0.48	2.8	51	24	25	13.5	4.86	0.82
WW05	0.7	1.2	2.4	6.8	0.32	0.28	2.2	46	21	33	5.7	0.67	1.06

APPENDIX 5-1C RUNOFF & OTHER VARIABLES

SITE	DRY RUN UNADJ RUNOFF (MM)	ADJ RUNOFF (MM)	WET RUN UNADJ RUNOFF (MM)	ADJ RUNOFF (MM)	ADJ TOTAL RUNOFF (MM)	TEST SLOPE (DEG)	LAND USE	HORIZON
CC03	2.86	0.00	2.93	0.00	0.00	30	1	4
CC04	3.98	0.44	4.49	0.95	1.38	30	1	4
CC06	3.75	0.21	4.54	1.00	1.21	30	1	4
CC07	3.00	0.00	3.42	0.00	0.00	30	1	4
CC08	4.38	0.84	6.46	2.92	3.76	30	3	3
CC09	11.45	7.91	15.90	12.36	20.26	30	3	3
CC11	14.65	11.11	23.75	20.21	31.33	30	3	3
CC12	11.12	7.58	19.80	16.26	23.84	30	3	3
CC13	23.67	20.13	23.63	20.09	40.21	30	3	3
CN01	2.28	0.00	9.37	6.89	6.89	10	2	3
CN03	7.30	3.76	17.07	13.53	17.28	30	3	3
CN05	3.79	0.25	3.54	0.00	0.25	30	1	4
CN06	4.51	0.97	5.64	2.10	3.07	30	3	3
CN07	2.25	0.00	2.63	0.21	0.21	3	3	3
CN09	5.90	2.36	10.06	6.52	8.88	30	3	3
CS01	2.23	0.00	2.16	0.00	0.00	3	2	1
CS02	2.40	0.00	2.93	0.51	0.51	3	3	3
CS04	3.26	0.78	3.16	0.68	1.46	10	2	3
CS05	3.40	0.92	4.90	2.42	3.34	10	3	3
CS07	5.72	2.18	7.61	4.07	6.24	30	2	3
CS08	3.60	0.06	6.28	2.74	2.80	30	1	4
PB01	2.49	0.00	2.98	0.00	0.00	30	2	1
PB02	4.04	0.50	3.36	0.00	0.50	30	2	1
PB03	2.62	0.14	1.77	0.00	0.14	10	2	1
PB59	3.38	0.96	2.69	0.27	1.24	3	2	1
PB60	3.39	0.91	2.87	0.39	1.30	10	2	1
PB61	2.08	0.00	2.11	0.00	0.00	10	2	1
PB62	2.91	0.49	2.69	0.27	0.77	3	2	1
PB64	1.97	0.00	2.04	0.00	0.00	10	2	1
PB65	2.78	0.30	2.61	0.13	0.43	10	2	1
PB66	6.15	2.61	5.13	1.59	4.21	30	2	3
PB67	2.84	0.36	2.36	0.00	0.36	10	2	1
PB68	5.68	2.14	5.72	2.18	4.32	30	2	1
PB69	2.25	0.00	3.12	0.64	0.64	10	2	1
PB70	5.22	1.68	5.34	1.80	3.49	30	2	1
PB71	2.44	0.00	2.68	0.20	0.20	10	2	1
PB73	2.89	0.41	2.79	0.31	0.71	10	2	1
PC13	2.17	0.00	2.08	0.00	0.00	3	2	1
PC14	6.30	2.76	8.85	5.31	8.07	30	2	3
PC15	2.15	0.00	2.36	0.00	0.00	3	2	1
PC16	5.02	1.48	5.57	2.03	3.51	30	2	1
PC17	5.77	2.23	5.56	2.02	4.2[illegible]	30	2	1
PC18	2.34	0.00	2.39	0.00	0.00	10	2	1
PC20	3.11	0.00	3.17	0.00	0.00	30	2	1
PC21	3.36	0.00	3.21	0.00	0.00	30	1	3
PC22	5.78	2.24	6.33	2.79	5.03	30	2	1
PC23	4.42	0.88	4.16	0.62	1.51	30	2	1
PC24	2.19	0.00	2.12	0.00	0.00	10	2	1
PC25	3.24	0.00	3.23	0.00	0.00	30	2	1
PC26	4.01	0.47	4.05	0.51	0.99	30	1	4

PC27	2.02	0.00	2.27	0.00	0.00	10	2	1
PC29	4.60	1.06	4.56	1.02	2.08	30	1	3
PC31	2.68	0.26	2.65	0.23	0.50	3	2	1
PC32	2.47	0.00	2.78	0.30	0.30	10	2	1
PC33	2.40	0.00	2.50	0.02	0.02	10	3	1
PC38	10.24	6.70	23.28	19.74	26.44	30	2	3
PC39	2.54	0.00	3.09	0.00	0.00	30	2	1
PC40	2.86	0.00	2.66	0.00	0.00	30	2	1
PC42	4.00	1.52	3.37	0.89	2.41	10	2	1
PR01	3.03	0.55	2.80	0.32	0.87	10	2	1
PR02	2.21	0.00	2.21	0.00	0.00	10	2	1
PR04	4.74	1.20	4.80	1.26	2.45	30	2	3
PR07	4.34	0.80	4.01	0.47	1.27	30	2	3
PR08	2.47	0.05	3.00	0.58	0.62	3	2	1
PR09	14.43	11.95	22.24	19.76	31.71	10	1	4
PR12	3.29	0.00	3.32	0.00	0.00	30	2	1
PR13	2.72	0.24	2.58	0.10	0.34	10	2	1
PS01	2.67	0.25	3.02	0.60	0.85	3	2	1
PS02	3.53	0.00	3.49	0.00	0.00	30	2	1
PS04	2.31	0.00	2.74	0.26	0.26	10	2	1
PS05	2.35	0.00	2.36	0.00	0.00	10	2	1
PS09	3.17	0.00	3.75	0.21	0.21	30	2	3
PS10	3.73	0.19	3.60	0.06	0.25	30	2	1
PS15	4.45	0.91	4.85	1.31	2.22	30	2	3
TC18	3.38	0.00	3.46	0.00	0.00	30	2	1
TC19	2.80	0.00	3.67	0.13	0.13	30	2	1
TC24	2.59	0.11	2.57	0.09	0.20	10	2	1
TC28	2.87	0.39	3.60	1.12	1.51	10	2	1
TC32	2.58	0.10	2.95	0.47	0.57	10	2	1
TC33	2.89	0.47	2.90	0.48	0.95	3	2	1
TC34	4.15	0.61	3.92	0.38	0.99	30	2	1
TC36	5.66	2.12	4.34	0.80	2.91	30	2	1
TC37	2.74	0.32	3.91	1.49	1.81	3	1	4
TC38	2.57	0.15	2.75	0.33	0.47	3	1	3
TE01	6.36	2.82	6.41	2.87	5.70	30	2	1
TE02	4.42	0.88	4.44	0.90	1.78	30	2	1
TE03	4.47	0.93	5.03	1.49	2.43	30	2	1
TE05	4.08	1.60	5.17	2.69	4.29	10	3	1
TE09	2.09	0.00	2.32	0.00	0.00	3	2	1
TE13	2.36	0.00	2.54	0.06	0.06	10	3	1
TE14	3.97	1.49	13.91	11.43	12.92	10	3	3
TE16	5.39	1.85	10.50	6.96	8.82	30	3	3
TM02	2.35	0.00	2.30	0.00	0.00	10	2	1
TM04	2.43	0.00	2.80	0.32	0.32	10	2	3
TM06	3.18	0.76	2.96	0.54	1.30	3	2	1
TM09	2.27	0.00	2.68	0.20	0.20	10	2	1
TM10	5.01	1.47	4.05	0.51	1.98	30	2	3
TM12	2.35	0.00	2.42	0.00	0.00	10	2	1
TN06	9.36	5.82	16.90	13.36	19.18	30	3	3
TN07	3.06	0.58	2.96	0.48	1.06	10	2	1
TN10	2.40	0.00	2.43	0.00	0.00	10	2	3
TN13	5.12	1.58	5.18	1.64	3.22	30	2	3
TW01	2.30	0.00	2.65	0.17	0.17	10	2	1
TW03	3.26	0.78	6.42	3.94	4.71	10	3	3
TW05	2.67	0.00	3.23	0.00	0.00	30	2	3
TW08	2.00	0.00	2.26	0.00	0.00	10	2	1
TW11	17.65	14.11	21.99	18.45	32.56	30	1	4
TW12	2.23	0.00	2.15	0.00	0.00	10	3	3
TW13	4.95	1.41	5.08	1.54	2.95	30	3	3
TW16	10.42	6.88	17.51	13.97	20.85	30	3	3

TW18	2.94	0.52	4.15	1.73	2.25	3	2	1
TW20	2.41	0.00	3.23	0.81	0.81	3	3	1
WA01	5.46	1.92	11.22	7.68	9.60	30	2	1
WA02	3.90	1.48	9.91	7.49	8.97	3	4	2
WA03	5.72	3.30	7.90	5.48	8.78	3	4	2
WA04	4.70	2.28	11.04	8.62	10.90	3	4	2
WC01	8.06	5.64	17.41	14.99	20.63	3	4	2
WC02	1.88	0.00	4.04	1.56	1.56	10	4	2
WC03	2.00	0.00	2.04	0.00	0.00	10	2	1
WC04	5.22	2.74	12.24	9.76	12.51	10	4	2
WC05	5.01	1.47	5.33	1.79	3.26	30	2	3
WC06	10.85	7.31	21.40	17.86	25.17	30	1	3
WC07	2.26	0.00	4.65	2.23	2.23	3	4	2
WC08	5.63	2.09	10.89	7.35	9.44	30	1	3
WC09	4.33	1.91	10.78	8.36	10.27	3	4	2
WM01	4.59	2.17	8.76	6.34	8.52	3	4	2
WM02	2.59	0.17	5.51	3.09	3.26	3	4	2
WM03	3.60	1.12	8.71	6.23	7.35	10	2	4
WM04	2.08	0.00	4.45	2.03	2.03	3	4	2
WM05	2.11	0.00	3.73	1.31	1.31	3	4	2
WM06	27.37	23.83	34.01	30.47	54.30	30	1	4
WM07	6.39	3.97	8.19	5.77	9.74	3	4	2
WM89	6.64	3.10	10.81	7.27	10.37	30	1	1
WM99	5.07	1.53	7.92	4.38	5.91	30	1	3
WM09	2.38	0.00	4.46	1.98	1.98	10	2	1
WM10	1.78	0.00	2.73	0.31	0.31	3	2	3
WM11	7.13	3.59	9.16	5.62	9.22	30	1	3
WS01	3.36	0.00	3.48	0.00	0.00	30	2	1
WM03	3.31	0.00	5.51	1.97	1.97	30	2	1
WS04	2.55	0.13	2.64	0.22	0.36	3	4	2
WS06	4.19	1.77	12.22	9.80	11.58	3	4	2
WS07	6.53	4.11	12.55	10.13	14.24	3	4	2
WS08	4.97	2.55	11.22	8.80	11.35	3	4	2
WS09	10.32	7.90	19.06	16.64	24.53	3	4	2
WS10	13.78	10.24	22.76	19.22	29.46	30	1	4
WS11	12.48	8.94	22.70	19.16	28.10	30	1	3
WW01	10.89	8.47	17.58	15.16	23.63	3	4	2
WW02	4.05	1.63	4.21	1.79	3.43	3	4	2
WW03	2.86	0.44	4.62	2.20	2.64	3	4	2
WW04	5.72	2.18	6.07	2.53	4.70	30	2	1
WW05	12.46	10.04	15.34	12.92	22.96	3	4	2

APPENDIX 5-2

TESTS OF NORMALITY OF SAMPLE DISTRIBUTIONS

To test the goodness of fit of sample distributions to normal curves having identical mean and standard deviation, the K-S one-sample test (Siegel 1956) was employed. The null hypothesis is :

$$H \ : F(O) = F(E)$$

while the alternative is

$$H \ : F(O) \neq F(E),$$

where F(O) is observed distribution and F(E) is expected distribution. |D | measures the maximum deviation of the observed from the expected cumulative frequency distribution. The hypotheses are tested at the 5 percent significance level and the results are presented in the following table.

APPENDIX 5-2 (cont'd)

Variable	TR	$\bar{x}$	s	n	$\lvert D\ max \rvert$	H_1
WAASHD	LOG	1.082	0.813	151	0.0705	Reject at 5%
SPASHD	LOG	1.961	0.533	151	0.0355	"
TOTALD	LOG	2.060	0.539	151	0.0435	"
WAASHW	LOG	1.397	0.797	151	0.0674	"
SPASHW	LOG	2.150	0.458	151	0.0796	"
TOTALW	LOG	2.268	0.487	151	0.0563	"
WAASHT	LOG	1.587	0.790	151	0.0881	"
SPASHT	LOG	2.378	0.481	151	0.0678	"
TOTALT	LOG	2.485	0.503	151	0.0464	"
WAASHV	LOG	0.676	0.685	99	0.0460	"
SPASHV	LOG	1.447	0.522	99	0.1241	"
TOTALV	LOG	1.551	0.515	99	0.0865	"
AGG	SQRT	5.710	1.637	148	0.0363	"
SAND	LOG	1.591	0.131	148	0.0645	"
CLAY	-	22.883	8.314	148	0.0749	"
OCC	SQRT	2.218	0.788	148	0.0590	"
CRSD	LOG	0.825	0.519	148	0.0432	"

TR = transformation; $\bar{x}$ = sample mean; s = standard deviation; n = sample size.

APPENDIX 6-1

PREDICTION OF WASH PROPORTION (Wp)

To predict Wp, a multiple regression equation was computed using Wp as the dependent variable and all other variables as independent variables :

$$Wp = 1.981 + 0.874(\tan\theta) + 0.013(U) - 0.045(G) + 0.006(Cy) \quad (6.6)$$

with $R^2 = 0.80$, and $n = 148$.

APPENDIX 8-1

DERIVATIONS & ASSUMPTIONS OF DATA MANIPULATION IN THE MULTIPLE REGRESSION MODEL

For the Multiple Regression Model:

$$Y_i = a + b_1 x_1 + b_2 x_2 + \ldots. + b_n x_n + \epsilon_i . \qquad (1)$$

Holding any one independent variable, (e.g. $X_i = k$), constant gives :

$$Y_i = a + b_1 k + b_2 x_2 + \ldots. + b_n x_n + \epsilon_i' \qquad (2)$$

Thus, Equation (2) - (1) gives :

$$Y_i' - Y_i = b_1 k - b_1 x_1 + \epsilon_i' - \epsilon_i$$

$$= b_1 (k - x_1) + (\epsilon_i' - \epsilon_i)$$

$$\text{or } Y_i' = Y_i + b_1 (k - x_1) + (\epsilon_i' - \epsilon_i) \qquad (3)$$

Strictly speaking, for each Y_i, $\epsilon_i' \neq \epsilon_i$ unless $\epsilon_i = 0$ for all Y 's. But for practical reasons, it is assumed that their difference is small so that

$$\epsilon_i' \doteqdot \epsilon_i$$

$$\text{and } Y_i' \doteqdot Y_i + b_1 (k - x_1) \qquad (4)$$

A second assumption is that only the independent variables have measurement errors but in actual fact there is at least a comparable amount of measurement error in the dependent variable.

For log transformed variables then,

$$\log(Y_i') = \log(Y_i) + b_1 (\log k - \log x_1)$$

$$\text{and } Y_i' = Y_i \times (k/X_1)^{b_1} \qquad (5)$$

APPENDIX 8-2

DEVELOPMENT OF MODEL B

Since RUNOFT was not used as part of the soil parameter in Model A, a new regression equation was computed dropping RUNOFT as the independent variable. The result for 148 laboratory data sets shows :

$$\log(CTT) = 4.58 + 0.40 \log(\sin\theta\cos\theta) - 0.19(G) - 0.26(C) - 0.005(Cy) - 0.15(\log Cs)$$

with $R^2 = 0.71$. CTT is corrected total loss.

APPENDIX 8-3 SOIL ERODIBILITY INDEX

SITE	TOTALP (G/SQ M)	TOTALQ (G/SQ M)	PINDEX
CC03	33.8	30.0	3.2
CC04	273.7	250.1	25.6
CC06	181.4	168.7	17.0
CC07	45.3	41.4	4.2
CC08	143.1	133.4	13.4
CC09	621.8	537.8	58.2
CC11	922.6	819.1	86.3
CC12	696.2	626.4	65.1
CC13	1324.8	1170.0	123.9
CN01	162.0	207.0	15.2
CN03	958.7	909.5	89.7
CN05	31.5	28.0	3.0
CN06	457.4	436.2	42.8
CN07	596.3	636.8	55.8
CN09	580.2	566.8	54.3
CS01	203.6	217.4	19.0
CS02	228.4	249.5	21.4
CS04	179.4	222.6	16.8
CS05	382.8	473.0	35.8
CS07	366.1	358.2	34.2
CS08	300.8	297.4	28.1
PB01	378.5	373.1	35.4
PB02	378.5	378.4	35.4
PB03	22.7	28.2	2.1
PB59	73.8	76.2	6.9
PB60	152.6	187.4	14.3
PB61	247.8	304.6	23.2
PB62	168.4	188.9	15.8
PB64	111.8	138.2	10.5
PB65	63.6	79.2	5.9
PB66	476.5	487.8	44.6
PB67	197.0	244.4	18.4
PB68	255.7	250.3	23.9
PB69	406.0	499.4	38.0
PB70	322.2	328.0	30.1
PB71	98.0	121.4	9.2
PB73	496.5	610.9	46.4
PC13	205.7	234.9	19.2
PC14	484.4	446.4	45.3
PC15	113.6	127.9	10.6
PC16	333.4	330.0	31.2
PC17	477.6	472.5	44.7
PC18	398.6	486.1	37.3
PC20	80.0	73.9	7.5
PC21	296.3	289.0	27.7
PC22	390.9	390.3	36.6
PC23	388.6	399.2	36.4
PC24	181.1	222.1	16.9
PC25	191.5	186.4	17.9
PC26	197.1	194.8	18.4
PC27	144.2	178.1	13.5
PC29	401.0	391.0	37.5
PC31	298.8	365.8	27.9

PC32	126.1	154.6	11.8
PC33	67.7	85.5	6.3
PC38	751.4	686.0	70.3
PC39	368.4	362.0	34.5
PC40	198.3	197.4	18.5
PC42	241.3	300.7	22.6
PR01	27.6	34.5	2.6
PR02	295.3	366.6	27.6
PR04	176.1	178.4	16.5
PR07	43.5	40.7	4.1
PR08	23.1	26.2	2.2
PR09	1164.9	1604.2	109.0
PR12	268.1	267.5	25.1
PR13	44.3	55.8	4.1
PS01	273.1	284.1	25.5
PS02	376.3	370.2	35.2
PS04	20.8	25.3	1.9
PS05	45.7	56.7	4.3
PS09	36.0	34.3	3.4
PS10	318.8	321.7	29.8
PS15	249.0	245.0	23.3
TC18	422.4	421.6	39.5
TC19	136.3	134.7	12.7
TC24	69.6	86.0	6.5
TC28	126.7	155.5	11.8
TC32	69.3	85.2	6.5
TC33	60.3	64.2	5.6
TC34	107.0	104.6	10.0
TC36	190.4	192.6	17.8
TC37	112.7	132.6	10.5
TC38	19.4	20.2	1.8
TE01	339.1	343.2	31.7
TE02	247.8	247.7	23.2
TE03	505.8	503.6	47.3
TE05	260.4	326.1	24.4
TE09	145.6	166.3	13.6
TE13	233.7	285.3	21.9
TE14	586.8	752.7	54.9
TE16	880.9	838.1	82.4
TM02	10.7	13.2	1.0
TM04	144.5	178.6	13.5
TM06	85.2	94.1	8.0
TM09	170.3	210.2	15.9
TM10	143.1	139.1	13.4
TM12	69.2	88.3	6.5
TN06	838.1	775.2	78.4
TN07	90.5	114.0	8.5
TN10	38.0	49.0	3.6
TN13	127.3	117.3	11.9
TW01	53.6	66.2	5.0
TW03	298.5	373.9	27.9
TW05	219.7	211.4	20.5
TW08	138.2	170.3	12.9
TW11	2264.3	1904.4	211.8
TW12	17.4	22.1	1.6
TW13	170.1	162.8	15.9
TW16	666.9	617.6	62.4
TW18	291.4	320.1	27.3
TW20	157.6	173.0	14.7
WA01	879.8	831.6	82.3

WA02	1035.1	1552.8	96.8
WA03	1584.0	1869.4	148.2
WA04	1343.2	2275.2	125.6
WC01	1823.8	3608.6	170.6
WC02	358.2	444.4	33.5
WC03	199.2	242.5	18.6
WC04	1490.2	1984.1	139.4
WC05	546.4	553.1	51.1
WC06	1211.0	1107.7	113.3
WC07	1285.6	1435.3	120.3
WC08	1076.9	1028.2	100.7
WC09	1645.2	2140.7	153.9
WM01	1586.1	1946.3	148.4
WM02	1397.4	1613.7	130.7
WM03	781.0	998.0	73.1
WM04	1477.6	1608.4	138.2
WM05	1175.4	1282.7	109.9
WM06	1689.8	1435.8	158.1
WM07	1308.2	1875.8	122.4
WM89	1027.4	973.5	96.1
WM99	831.4	819.2	77.8
WM09	340.5	425.4	31.9
WM10	1023.2	1101.9	95.7
WM11	748.0	754.7	70.0
WS01	543.0	545.0	50.8
WM03	688.3	675.3	64.4
WS04	456.7	488.1	42.7
WS06	1771.4	2256.8	165.7
WS07	1876.8	2942.6	184.9
WS08	977.5	1673.1	91.4
WS09	1728.8	3949.0	161.7
WS10	1065.7	958.2	99.7
WS11	1152.4	1045.2	107.8
WW01	1184.5	2397.9	110.8
WW02	593.6	725.7	55.5
WW03	1279.0	1425.9	119.6
WW04	450.6	452.3	42.1
WW05	1222.2	2318.5	114.3
